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Project 8.4-1

PROTECTION AFFORDED BY OPERATIONAL SMOKE SCREENS AGAINST THERMAL RADIATION

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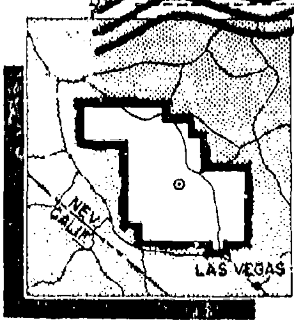

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OPERATION KNOTHOLE

Project 8.4-1

PROTECTION AFFORDED BY OPERATIONAL SMOKE SCREENS AGAINST THERMAL RADIATION

REPORT TO THE TEST DIRECTOR

C.J. Monte for Chief, ISCM, DNA

by

Elmer H. Engquist
Charles W. Forsthoff, Capt, Cml C

March 1954

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ABSTRACT

The original objective of Project 8.4-1 was to evaluate the attenuation, by an operational fog oil smoke screen, of the thermal radiation resulting from the detonation of a nuclear device, and to collect data to verify the theoretical calculations on the above being developed concurrently under contract to the Chemical Corps.

It was originally planned to conduct this evaluation on Shot 9 with an operational smoke screen set-up with smoke generators, and/or smoke pots. Thermal flux data were to be obtained under the smoke screen at distances varying from 2500 to 6500 ft from ground zero of the nuclear device detonated 2420 ft in the air. Adverse wind conditions and possible interference with the overall test program under these wind conditions resulted in the last-minute cancellation of the smoke screen test.

With instrumentation recovered from Shot 9, and new instrumentation fabricated in the interim period, a preliminary evaluation was rapidly planned for Shot 10. The objective of this evaluation was to obtain partial data for the preliminary analysis of the Thermal Radiation Attenuating Clouds (TRAC) program and to obtain data applicable to future planning for a full-scale evaluation of an operational smoke screen. A single instrumentation station was located at a slant range of 2238 ft from the detonation of the nuclear device approximately 500 ft in the air. The smoke screen for this test was established with 175 smoke pots which ringed the station on a 200 ft and 300 ft diameter ring.

Analysis of the photographic records of the test has shown that the carbon smoke screen, also set up on Shot 10, intercepted the thermal radiation incident upon the fog oil smoke screen evaluated by this project. This carbon smoke screen, therefore, contributed to the reduction of thermal radiation measured at the single instrumentation station. The photographs enabled some estimation of the reduction due to the carbon and fog oil smoke screens individually.

The measured thermal flux in the direction of air zero with 180° field of view calorimeters was 0.8 ± 0.1 cal/sq cm at a single station located 2238 ft from air zero. The measured flux with two other types of instruments was less than 0.7 cal/sq cm. The incident thermal flux, without smoke present, at this distance was 57.5 ± 5.0 cal/sq cm. The attenuation of radiant energy by the carbon and fog oil smoke was therefore 98.6 ± 0.3 per cent. Based upon the attenuation of radiant energy

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measurements made solely on the carbon smoke it has been estimated that the carbon smoke screen reduced the incident thermal radiation from 57.5 to 6.8 cal/sq cm. The estimated attenuation of thermal radiation by the fog oil smoke screen was, therefore, from approximately 6.8 to 0.8 cal/sq cm, or 85 to 90 per cent.

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FOREWORD

This report is one of the reports presenting the results of the 78 projects participating in the Military Effects Tests Program of Operation UPSHOT-KNOTHOLE, which included 11 test detonations. For readers interested in other pertinent test information, reference is made to WT-782, Summary Report of the Technical Director, Military Effects Program. This summary report includes the following information of possible general interest.

a. An over-all description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the 11 shots.

b. Compilation and correlation of all project results on the basic measurements of blast and shock, thermal radiation, and nuclear radiation.

c. Compilation and correlation of the various project results on weapons effects.

d. A summary of each project, including objectives and results.

e. A complete listing of all reports covering the Military Effects Tests Program.

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PREFACE

The thermal radiation attenuation studies reported herein were undertaken by the Chemical Corps to determine the feasibility of minimizing by fog oil smoke screens the effects of thermal radiation from the detonation of a nuclear device.

In the detonation of a nuclear device in a clear atmosphere the thermal radiation is received on a direct line upon any surface facing the source. By introducing a fog oil smoke screen between the detonation point and objects within or beneath the screen this direct radiation is reflected and scattered. The results of this scattering, therefore, should be to decrease markedly the amount of radiation received on an object within or beneath the screen to a value sufficient to minimize burn-production or fire-ignition.

A full-scale evaluation was scheduled for conduct on Operation UPSHOT-KNOTHOLE, Shot 9 (8 May), but was cancelled just prior to detonation because of adverse wind conditions and possible interference with the overall test program. The complete test planned for Shot 9 was to provide all the data necessary for field evaluation of operational screens and verification of the theoretical calculations being developed concurrently. A limited evaluation was then rapidly planned for Shot 10 (25 May), to obtain partial data for the preliminary analysis of the Thermal Radiation Attenuating Clouds (TRAC) program and obtain data applicable to planning for a future full-scale evaluation of an operational screen. It is believed that the information obtained from this study will assist in evaluating this protective measure, available to the Department of Defense and the Federal Civil Defense Administration, for the protection of material and personnel from the thermal effects resulting from such a detonation.

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ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance rendered by Mr. Thomas Mcnahan and the staff of the Naval Material Laboratory in furnishing guidance and advice in the construction of the cosine law attenuator calorimeters used for measuring the thermal flux under the smoke screen and in making the spectral measurements on radiant energy received under the smoke screen; and, to acknowledge the assistance rendered by Dr. Andrew Guthrie and the staff of the U. S. Naval Radiological Defense Laboratory in making the supporting measurements on the spatial distribution of radiant energy under the smoke screen, and in providing the basic thermal flux versus distance outside the smoke screen.

In addition, the assistance of many groups within the Chemical and Radiological Laboratories contributed to the prosecution of this project. In particular, the work of the groups under Mr. J. C. Smith and Mr. Frank Whitney on the development, construction, installation, and operation of the smoke generators and smoke pots, under Lt Colonel Charles Robbins, Dr. J. J. Mahoney, and Mr. Robert B. Price on the development of the gas calorimeter, and under Capt Charles W. Forsthoff, Cml C, on the construction of the cosine law attenuator calorimeters should be acknowledged.

Finally, the assistance of Prof. Phillip Leighton and Dr. William Perkins of Stanford University, in their pretest study of micrometeorological information and test site conditions, was in no small measure responsible for the development of an adequate experimental layout of smoke generators and smoke pots for this project.

The project officer particularly appreciates the guidance, advice, and assistance of LCDR R. G. Preston, Director, Program 8, in the planning and conduct of this experiment.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The original objectives of Project 8.4-1 were to evaluate the attenuation, by an operational fog oil smoke screen, of the thermal radiation resulting from the detonation of a nuclear device, and to collect data to verify the theoretical calculations on the above, being developed concurrently under contract to the Chemical Corps.

Following the cancellation of the original experiment, a limited experiment was designed, using a single instrumentation station with a fog oil smoke screen established by smoke pots, with the following objectives:

(1) To collect limited data to verify the theoretical calculations

(2) To collect limited data to indicate the potential effectiveness of an operational fog oil smoke screen in attenuating thermal radiation

(3) To proof-test instrumentation methods and test procedures and,

(4) To obtain data applicable to the planning of a possible future full-scale evaluation of an operational screen.

The purpose of this study was to determine the effectiveness of an oil fog smoke screen in scattering thermal radiation. In a clear atmosphere, thermal radiation normally reaches an object on a direct line from the bomb source. By introducing a smoke screen the radiation is scattered away from objects within the screen, and the radiation which reaches the object does so from many directions, thereby minimizing burn-production and fire-ignition.

1.2 HISTORICAL

The basic concepts of the protection from thermal radiation produced by the detonation of a nuclear device were initially proposed by Condit et al. 1/ From their studies they concluded that a smoke screen is a measure which can be quickly applied over a large area for use in an emergency. Hulbert et al 2/ analyzed the effects of fog, clouds and

smoke on thermal radiation from atomic bombs and concluded that fog or smoke around the target reduces the thermal radiation to a point where the reduction is of practical importance. They also stated that special experimentation would not only be difficult to perform, but would contribute little to what may be derived from present knowledge.

Brown and Goshe 3/ used the sun as a source of thermal radiation and experimentally determined that fog oil smoke screens produced by M2 smoke generators reduced the solar radiation from 50 to 90 per cent, depending upon the concentration. They recommended a study be made at the Nevada Proving Grounds using operational fog oil smoke clouds to obtain more accurate operational data.

In October, 1951, the Chemical Corps requested a test project for Operation TUMBLER-SNAPPER in the spring of 1952 to evaluate the effectiveness of fog oil smoke screens against thermal radiation. This request was deferred by action of the Armed Forces Special Weapons Project (AFSWP) and the Research and Development Board as being more suitable for conduct at Operation KNOTHOLE scheduled for the spring of 1953. A preliminary test of methods and procedure to be used in the KNOTHOLE evaluation was originally approved for Operation UPSHOT, planned for the fall of 1952. UPSHOT was subsequently deferred and the preliminary test requirement cancelled.

Project East River 4/ made a study of the feasibility of using thermal radiation attenuating clouds. In their report to the Secretary of Defense, The Chairman, National Security Resources Board and The Administrator, Federal Civil Defense Administration, it was stated that the use of a fog oil smoke cloud for shielding against radiant energy offered such great promise that their recommended research program should be implemented without delay. This report is known as the TRAC Report published by the Associated Universities, Inc.

In February, 1952, The Chief, Special Projects Office, Chemical Corps Research and Engineering Command, in an unnumbered memorandum to The Commanding General, Chemical Corps Research and Engineering Command, recommended that the Chemical Corps immediately initiate a project to develop the programs outlined in the TRAC Report. Subsequent meetings between the Assistant Chief of Staff, G-4, AFSWP, and the Chemical Corps resulted in directives from these two agencies authorizing the Chemical Corps to initiate meteorological studies, theoretical investigations, and field tests to determine the effectiveness of thermal radiation attenuating clouds.

Laboratory studies were also initiated at the Army Chemical Center employing a searchlight source of radiation in a large warehouse (approximately 75 ft long, 35 ft wide and 20 ft high) used as a smoke cell. Measurements made under these conditions indicated that approximately 70 to 80 per cent attenuation of thermal radiation could be expected from a 100 ft path length of oil fog aerosol of 20 to 26 micrograms per liter concentration. Based upon this and additional data preliminary calculations were made of the radiation to be expected beneath the oil fog screen on the UPSHOT-KNOTHOLE tests. 5/

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1.3 THEORETICAL

The mechanics of the generation of radiant energy by the detonation of a nuclear device have been described. 6/ Its propagation through the atmosphere has been studied, both theoretically 7/ and experimentally. 8/ 9/ 10/ 11/ However, these studies have been primarily concerned with unidirectional flux undergoing normal atmospheric attenuation by scattering and absorption.

When a fog oil aerosol is placed between the source and receiver, radiant energy attenuation is markedly increased. Since this aerosol is composed of fog oil droplets which are essentially transparent scattering bodies, 12/ the attenuation is principally a parameter of multiple scattering and depends to a much lesser extent upon the absorption function.

Measurements of the incident and transmitted radiant energy can readily be made. However, with a scattering smoke screen the field of view of the detectors used to determine the transmittance is of considerable importance. Measurement of incident radiation is the measurement of a unidirectional flux, since air scattering is essentially negligible. Measurement of the transmitted radiation beneath a smoke screen is the measurement of a multidirectional flux. Thus, the ratio of transmitted to incident radiation, or the transmittance, is not a dimensionless quantity. The use of collimated detectors with identical fields of view would satisfy the requirements for a dimensionless quantity, but fail to give a complete description of the reduction of thermal radiation afforded by the aerosol. Any transmittance will be valid only for the particular spatial orientation of the collimated detectors and consideration must be given to the contribution of all spatial orientations of such detectors.

The thermal effects upon any unit area of a plane surface oriented in space is a function of such parameters as distance, total energy, and rate of delivery. Under field test conditions without smoke present, the incident beam, although undergoing a measurable amount of scattering and absorption, can be considered a unidirectional flux if the distance is small compared to the visibility. Any detecting instrument having a limited field of view will thus receive the major portion of the flux.

When the incident radiation impinges upon a fog oil aerosol, scattering which occurs in the upper layers causes some of the radiation to leave the aerosol cloud. This is referred to as reflection or albedo. The radiation which penetrates into the aerosol cloud is multiply scattered. The radiant energy which will eventually irradiate any unit plane surface in or below the fog oil aerosol can arrive at this surface through a maximum angle of 2π steradians. Since the reception of radiant energy is of short duration, the thermal effects on any unit area plane surface in or below the cloud will be a function of the total integrated flux over an angle of 2π steradians.

If the transmittance is defined as the ratio of the cumulative fluxes received with and without smoke present over an angle of 2π steradians by unit area plane surfaces having the smoke orientation, and the spatial distribution of the radiant energy is determined, a more

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realistic interpretation of the true attenuation afforded by an oil fog aerosol can be made. For this reason instruments as described in later sections were constructed so that they would have fields of view as closely approaching an angle of 2 π steradians as feasible.

To obtain a verification of the flux measured in various spatial orientations by detectors having an angle of view of 2 π steradians, a 4 π geometry detector was also employed at a limited number of stations.

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CHAPTER 2

EXPERIMENTAL PROCEDURE

2.1 GENERAL

This evaluation was originally scheduled for conduct on Shot 9 (8 May). For this test an atomic weapon of approximately nominal yield was to be air-dropped and detonated at an altitude of 2400 ft. The entire area east of a north-south line through ground zero was assigned for the conduct of this project.

Following the cancellation of the smoke screen experiment on Shot 9, a limited experiment was designed with a single partially instrumented station located 2166 ft from the planned ground zero for Shot 10. Smoke pots were used to provide a smoke screen over this single station. A nuclear device was detonated at 500 ft over ground zero for this shot.

2.2 TEST LAYOUT

2.2.1 Full Scale Evaluation - Shot 9

On the basis of preshot planning information furnished by the Directorate of Weapons Effects Tests, the instrumentation station layout specifically for this project was established as shown in Fig. 2.1. Three major instrument stations were located on the smoke line at 2500, 4500, and 6500 ft from the planned ground zero. Two secondary instrument stations were located on the smoke line at 3500 and 5500 ft from the planned ground zero. Three secondary instrument stations were located on the blast and thermal instrument line outside of the smoke screen at 2500, 4000, and 5000 ft from the planned ground zero. These stations were in addition to the basic thermal instrument line stations.

As the primary source for production of a smoke screen 50 E19R3 smoke generators were placed on a line approximately 1000 ft north and parallel to the smoke instrumentation line and on an arc of 1000 ft radius southwest, west and northwest of the 2500 ft station. Due to the lack of complete micro-meteorological information construction for an alternate generator line was established 1000 ft south and parallel to the smoke instrumentation line. This latter generator line was used for all preliminary smoke screen experiments. This layout of primary and

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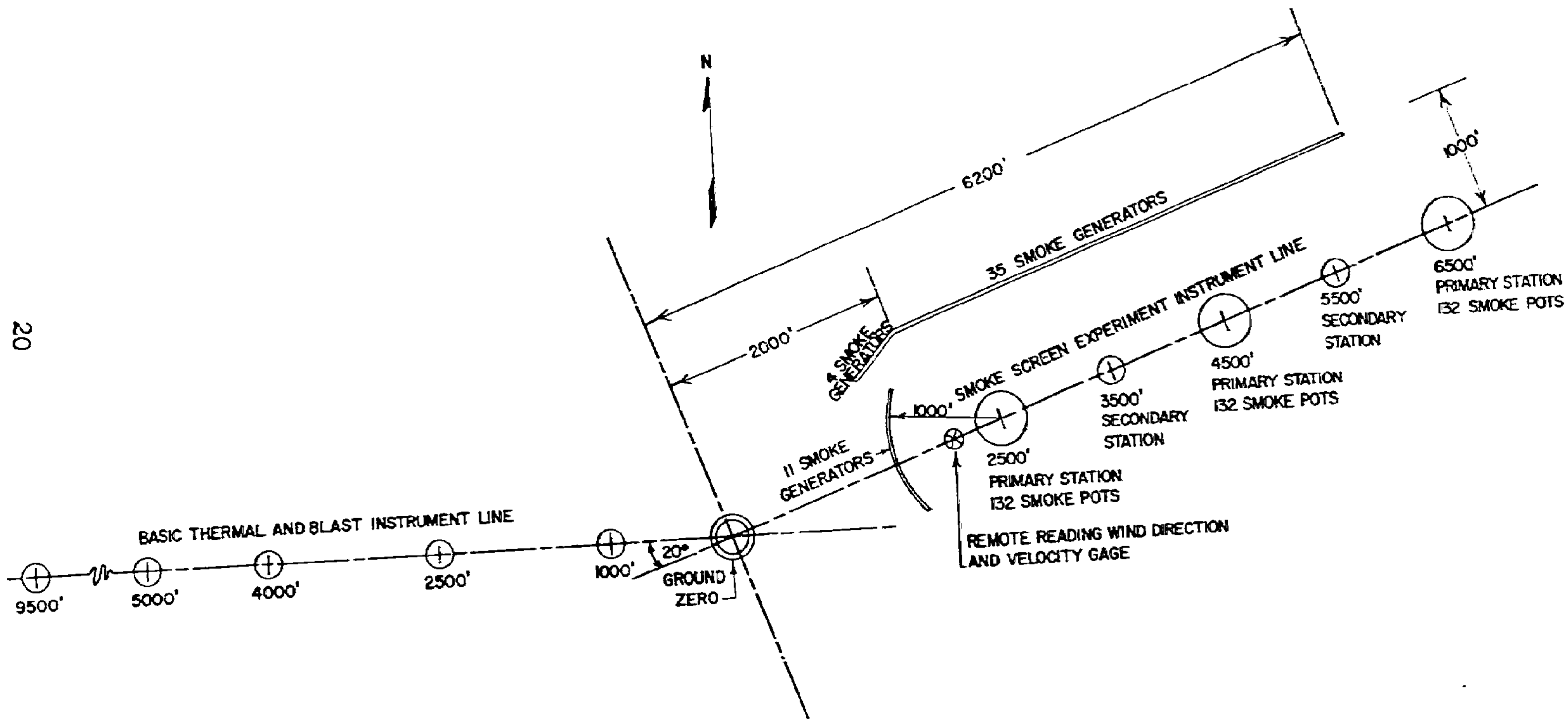

Fig. 2.1 Thermal Instrumentation Layout - Shot 9

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and secondary generator pit locations is shown in Fig. 2.2. In the event adverse wind conditions prevented the firing of part or all of the generators the three primary instrument stations were each ringed with a primary ring of 72, and a secondary ring of 60 Smoke Pots, Floating, MK 5, Mod. 2 on a 150 ft radius circle. Firing of the smoke pots and the E19R3 generators was controlled from the control point with a selective firing system of five manually operated circuits.

One set of remote reading wind direction and velocity gages was installed 2200 ft from ground zero on the smoke instrumentation line. The gages were mounted on a 30 ft pole. This equipment provided a reading in the control point of local wind direction and velocity in the test area. The two E19R3 generators closest to ground zero were connected to a separate circuit to provide smoke during the wind run of the bomb-drop aircraft. The observation by the bombardier of ground zero over this preliminary smoke plume and the observation of the smoke plume behavior by a ground observer, coupled with the observation of the wind direction and velocity gage reading, was to assist the Technical Director of the Military Effects Group in determining the smoke pots and/or generators to be fired.

A complete listing of the instruments and measurements made at each station is given in Table 2.1.

TABLE 2.1 - Station Instrumentation and Measurements

Station No.	Distance from GZ (ft)	Instrumentation			Measurements		
		CRL Ball Calorimeter	USNRDL Disc Calorimeter	NML Cosine Law Attenuator Calorimeter	Spectral Distribution	Spatial Distribution	Total Flux
F-424	2500	x	x	x	x	x	x
F-428	3500	x					x
F-429	4500	x	x	x	x	x	x
	5500	x					x
F-430	6500	x		x	x	x	x
F-202	2500	x	x				x
F-208	4000	x	x				x
F-210	5000	x	x				x

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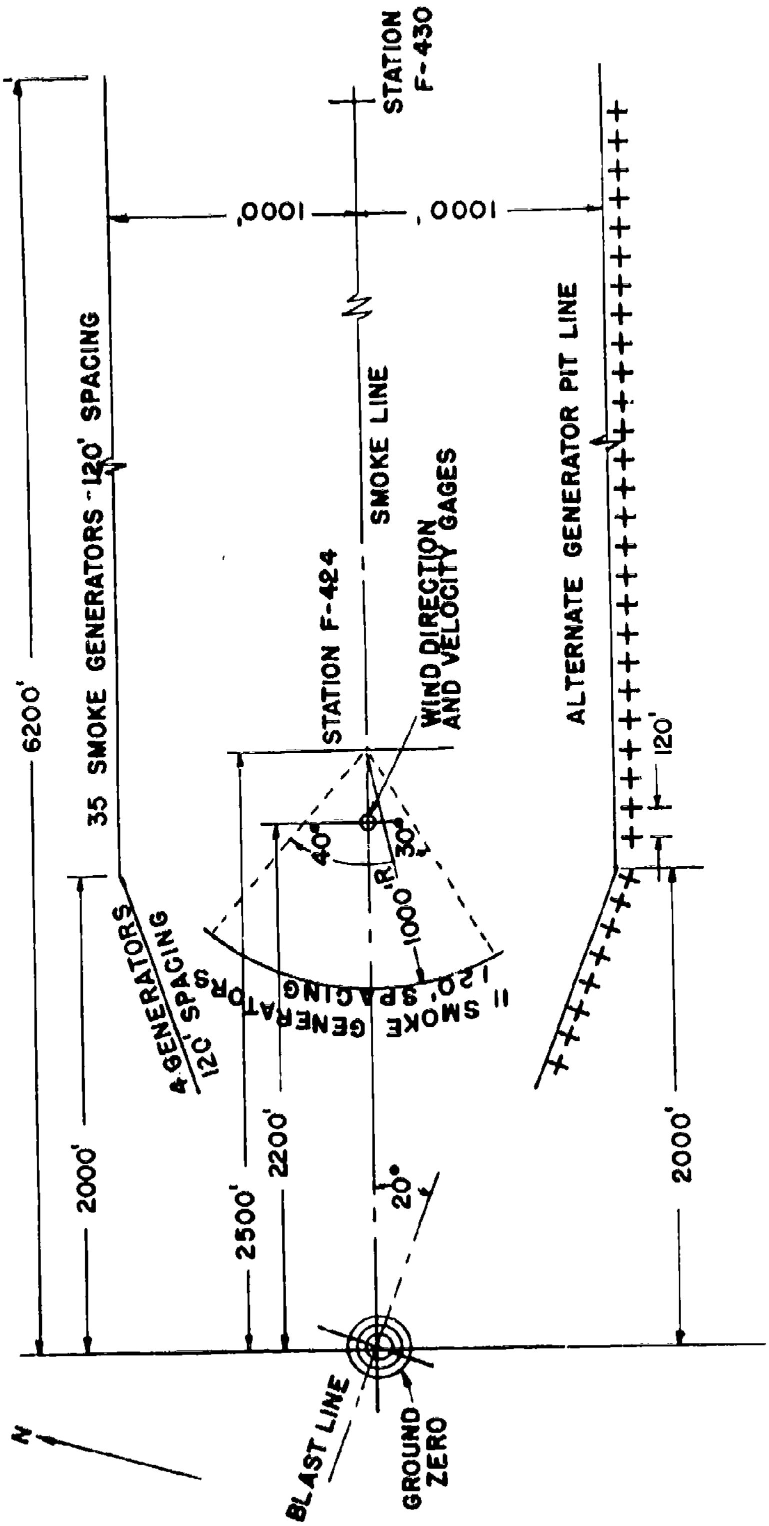

Fig. 2.2 Smoke Generator Plot Plan - Shot 9

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2.2.2 Preliminary Experimental Evaluation - Shot 10

A preliminary experiment was designed to obtain a limited amount of data after the cancellation of the test planned for Shot 9. One station was located 2166 ft from the planned ground zero on a true bearing of 120°, southeast from ground zero. This location was 2205 ft from the actual ground zero. The slant range from air zero to this station was 2238 ft. The location was chosen since the expected peak overpressure and thermal radiation were approximately the same as previously expected at the 2500 ft station on Shot 9.

This station was instrumented with one U. S. Naval Radiological Defense Laboratory disc calorimeter assembly in a goniometric pattern, using three π steradian field of view detectors and nine 2 π steradian field of view detectors; with two maximum indicating Chemical and Radiological Laboratories ball calorimeters; with two electrically recording C&RL ball calorimeters; with two complete Naval Material Laboratory cosine law attenuator calorimeter installations; and with one Naval Material Laboratory passive receiver assembly for spectral measurements.

To provide smoke, Smoke Pots, Floating, MK 5, Mod. 2 were set out on two concentric rings 200 ft and 300 ft in diameter around the instrumentation station. Ninety-three Smoke Pots were located on the 300 ft diameter ring. There were one hundred sixty-five smoke pots located on the 200 ft diameter ring, with alternate smoke pots connected to each of two firing circuits. One of the two 200 ft ring firing circuits was also connected to the ninety-three smoke pots on the 300 ft ring. Thus, either ninety-three smoke pots on the 300 ft ring and eighty-three smoke pots on the 200 ft ring, or eighty-two smoke pots on the 200 ft ring could be fired, depending upon the wind conditions and the smoke concentration desired.

2.3 THERMAL INSTRUMENTATION

2.3.1 Ball Calorimeters

This instrument is a modification of the Naval Research Laboratory gas calorimeter. A U-type pressure indicator has been substituted for the original bellows type. The gas pressure increase due to absorption of radiant energy by the blackened copper shell of the calorimeter is directly related to the amount of incident radiant energy. The supporting neck of the ball has been redesigned so that only 2.4 per cent of the surface area of the ball is unaffected by radiant energy and it essentially receives radiation from a 4 π steradian field of view. Recording devices are of two types:

1. Maximum thermal flux recorder
2. Continuous thermal flux electrical recorder

The maximum thermal flux type ball calorimeter measures the total thermal radiation incident on its spherical detector. The U-type pressure

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indicator is partially filled with a solution of 20 gm of K_2CO_3 in 100 gm of water. As this liquid is pushed up on one side of the tube it dissolves a coating of methyl red dye which originally coats the inside of the tube. On cooling to ambient temperature, the sharp line at the maximum attained by the K_2CO_3 solution marks the pressure increase over atmospheric. Figure 2.3 shows the components of the gas calorimeter and Figs. 2.4 and 2.5 show the field installation.

Two bleeder tubes are provided to eliminate fluctuations in the manometer due to atmospheric pressure changes. The bleeder tube for the asbestos-wrapped steel cylinder, shielding the manometer from blast damage, is a No. 27 B-D Yale hypodermic needle. The bleeder tube for the blackened copper ball is a calibrated glass capillary tube. For thermal shielding the manometer shielding cylinder is lined with 1/4 in. asbestos. Due to the large volume, 1200 ml, of the steel shielding cylinder, the effect of the blast wave through the bleeder tube is considered negligible.

For measuring the higher thermal fluxes, mercury is substituted for the K_2CO_3 solution. On the methyl red side of the U-tube the mercury is covered with a 0.5 cm column of K_2CO_3 solution to dissolve the methyl red and record the maximum height obtained. Manometers filled only with K_2CO_3 solution have 1 milliliter of di-2-ethyl-hexyl phthalate (DOP) floated on the side of the U-tube connected to the ball calorimeter. This DOP has a negligible vapor pressure and minimizes the escape of water vapor into the ball. The DOP has a specific gravity of 0.9861 at 20°C and a boiling point of 386°C at 760 mm of mercury.

For the continuous recording of the pressure change as a function of time, a high resistance electrolyte was floated on the indicating side of the U-tube. This electrolyte consisted of two grams of $CuSO_4$ in 100 gm of water and 10 cc of 95 per cent ethyl alcohol. The alcohol minimizes polarization and acts as an antifreeze in the event there were freezing temperatures at the test site. This solution results in an electrolyte of approximately 1000 ohms resistance per linear centimeter in the U-tube column. The variable length $CuSO_4$ solution is in series with an Esterline-Angus recorder of approximately 1400 ohms resistance. It has an operating voltage of 2.4 volts and is powered by a 24-volt battery. Figure 2.6 shows the installation of the recorder and accessories in the field.

2.3.2 Cosine Law Attenuator Calorimeter

The Naval Material Laboratory (NML) cosine law attenuator calorimeter, shown in Fig. 2.7, was used to measure the spatial distribution of the radiant energy. The calorimeter is designed to expose two paper or fabric indicator strips, 3/4 in. wide, around the circumference of a 1 1/2 in. white pine semi-circle 18 in. in diameter. A 1/8 in. groove is milled into the curved face of the wood on the units mounting paper indicators. The milled air space is not used beneath fabric indicators. In assembly of a unit, three 1/4 in. wide quinterra asbestos paper strips are laid on the edges of the two indicator papers and held in place by 1/4 in. wide 23 gage aluminum straps. Each aluminum strap is drawn tight and attached to the wooden support with 10 brass escutcheon

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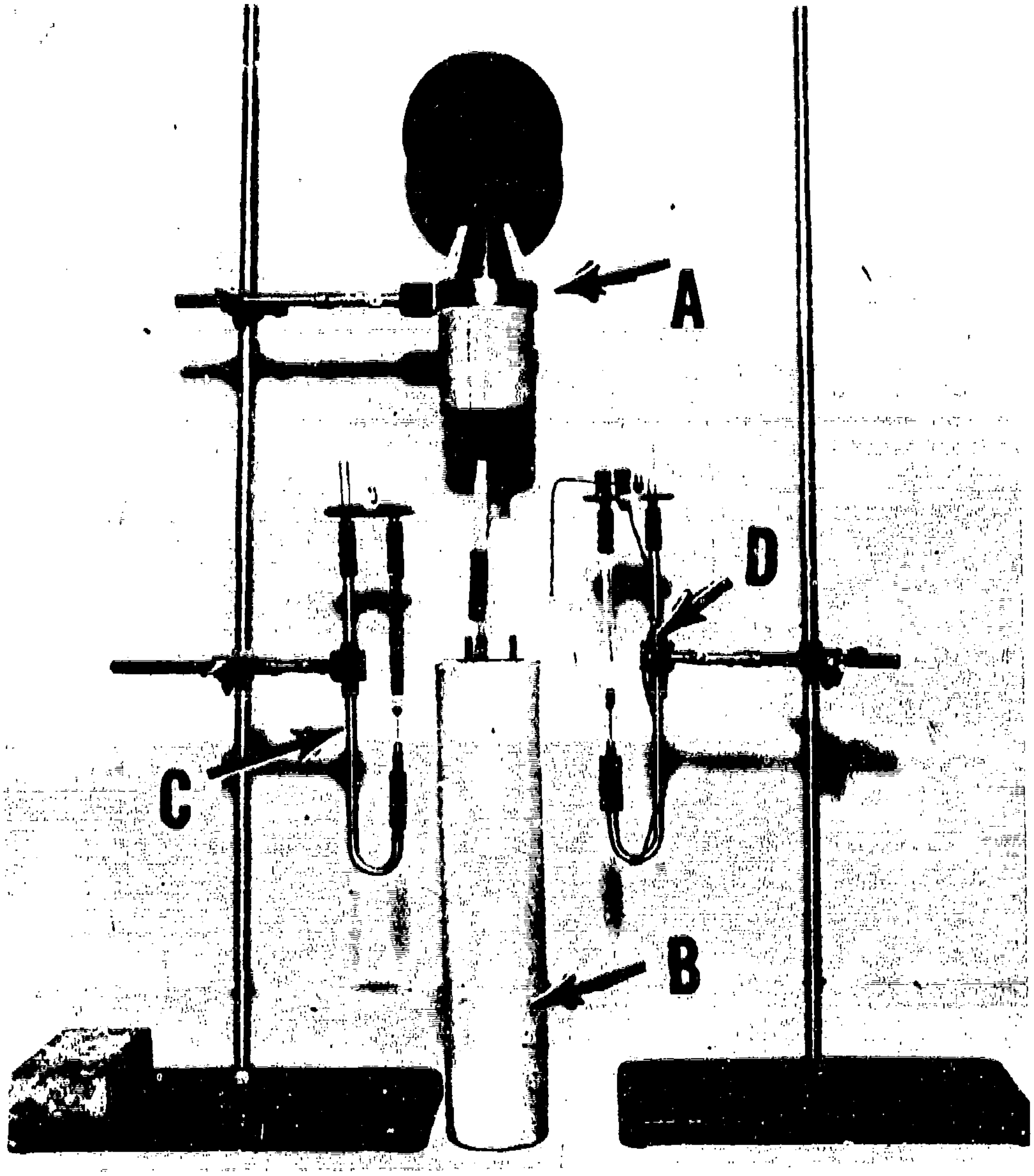

Fig. 2.3 - Components of the Gas Calorimeter

A. Detector Head and Neck Assembly
B. Manometer Shielding Cylinder
C. Maximum Thermal Flux Recording Manometer
D. Continuous Thermal Flux Electrical Recording Manometer

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Fig. 2.4 - Field Installation of Ball Calorimeter on 6 ft Pole

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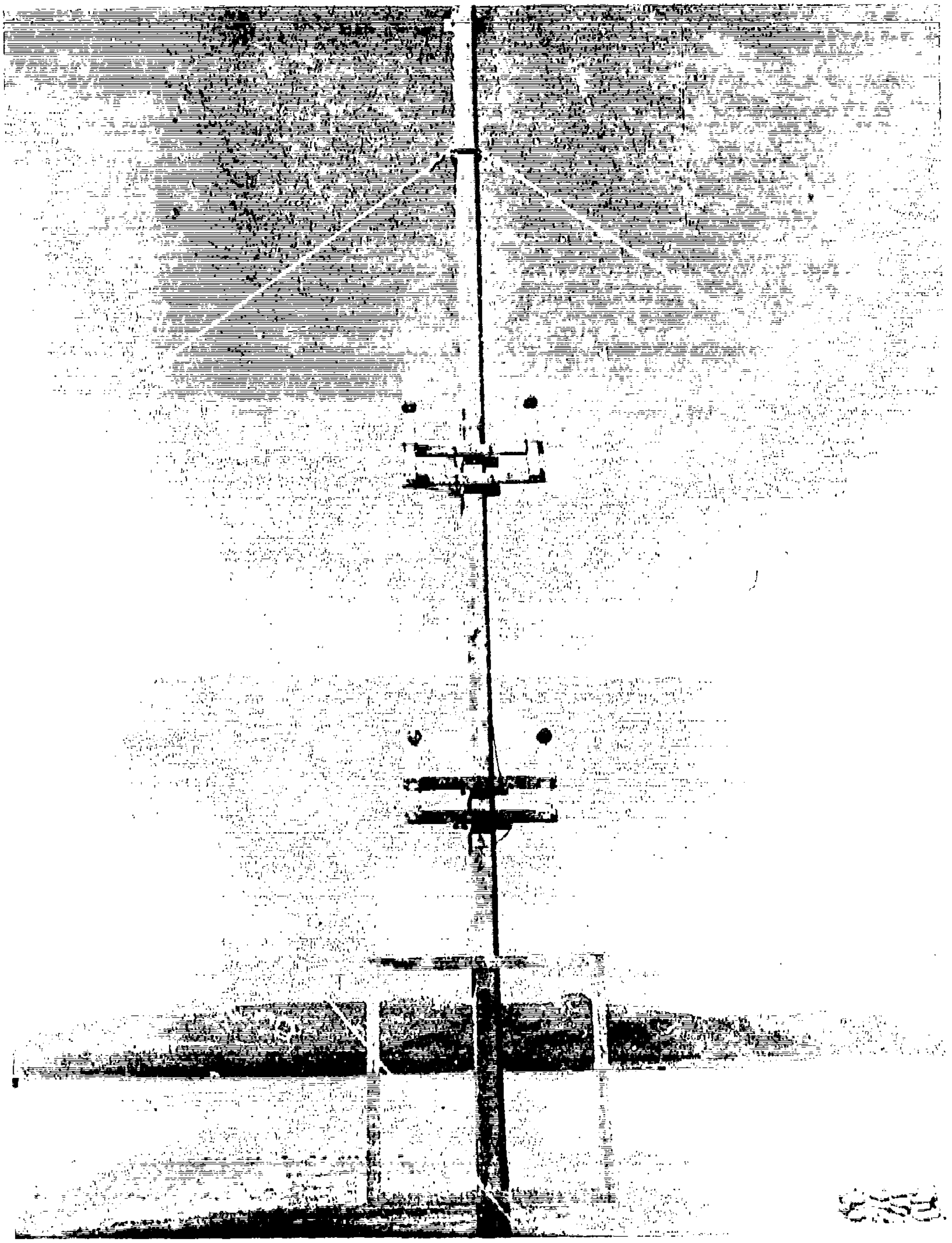

Fig. 2.5 - Field Installation of Ball Calorimeter on 25 ft Pole

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Fig. 2.6 - Field Installation of Esterline-Angus Recorder and Accessories

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Fig. 2.7 Cosine law Attenuator Calorimeter

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pins. To prevent the propagation of a flame, the indicator strips are striped with Albi Temp Kote "99" white fire-retardant paint, dividing the exposed length of indicator paper or fabric into 3/16 in. sections.

A total of eight different papers and fabrics are mounted on four units to form a stack for one measurement. The observed thermal effects and critical energies of these materials as determined from laboratory calibrations are given in Table 2.2.

A more detailed description of the cosine law attenuator calorimeter and the methods of calibration are given in the TUMBLER-SNAPPER Report, Project 8.3a 9/ and Naval Material Laboratory Report No. 5046-33. 12/

Figures 2.8 and 2.9 show the methods of field installation.

2.3.3 Field Calorimeter

The U. S. Naval Radiological Defense Laboratory (NRDL) field calorimeter is basically a disc-shaped energy receiver, cut from copper and blackened on one face with electrolytically deposited platinum and finished with camphor black. Soldered to the center of the unblackened face of the disc is a thermocouple consisting of 5 mil diameter copper and constantan wire. The other end of the thermocouple wire is fastened to the cold junction massive copper blocks housed in the calorimeter case. The electrical signal generated by the thermocouple is fed into one galvanometer of a 12-channel Heiland Oscillograph Recorder.

At the request of the Chemical and Radiological Laboratories the original π -steradian field of view calorimeter has been modified to provide an essentially 2 π -steradian field of view. The π -steradian field of view calorimeter is exposed to thermal radiation through an appropriate quartz filter. The 2 π -steradian field of view instrument has no filter and is protected by a dust cover. This cover consists of a 4 in. diameter spring loaded aluminum disc held in place by a nichrome wire. A signal from the Edgerton, Germershausen & Grier (EG&G) relay actuates an Agastat electropneumatic time delay relay which permits current to flow through the nichrome wire, burning same, and permitting the dust cover to be ejected by spring pressure away from the blackened disc of the field calorimeter.

Detailed information on the operation, calibration and field installation of the field calorimeter is given in the BUSTER report for Project 2.4-1. 8/

2.4 SPECTRAL DISTRIBUTION INSTRUMENTATION

2.4.1 Passive Receivers

The spectral distribution of the radiant energy among three broad, representative wave length regions was measured with passive receivers by NML. These receivers are in the form of metal foils mounted behind quartz windows and behind each of two selected glass filters. The metal foils, 2 mm wide, 16.5 mm long, are made of lead, zinc, tin, nickel, gold, platinum, and palladium in thicknesses from 1 to 5 mils. The purpose of the quartz window is to eliminate effects of

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TABLE 2.2 Critical Thermal Energies of Passive Indicators

Type	Material	Thermal Effect	Critical Energy Cal/cm^2 Air Background
III	Carbon Paper, Medium Finish, Black. Lightweight	Destruction	0.84
III	Sanborn Recording Permapaper	Destruction	2.2
II	Paper, Matte, Black	Destruction	2.4
II	Paper, 25% Rag Bond, Cherry	Charring Destruction	7.2 10.0
I	U. S. Postal Card Paper, Manila	Charring Destruction	15.0 17.0
I	Paper, 25% Rag Bond, Yellow	Charring Destruction	11.0 18.0
IV	Cloth, Cotton, Wind Resistant Poplin, 5-7 oz/sq yd, O.D. #7	Charring Destruction	— —
IV	Cloth, Herringbone Twill, Green 9.0 oz/sq yd	Charring Destruction	— —

weathering and other local disturbances. The transmissivity of the quartz filter permits a study of the significant radiation between 2200 and 30,000 A°. The two filters employed, Corning 3060 and 2550, pass all radiation in that region beyond 4000 and 8500 A°, respectively. The foils are mounted on a grooved glass melamine block, providing for a suitable air gap in front of and behind the foils, as shown in Fig. 2.10. The field installation of a complete unit is shown in Fig. 2.11.

Detailed information on the passive receivers is given in the BUSTER report for Project 2.4. 14/

2.4.2 Field Calorimeter

The NRDL field calorimeter was also set up to determine the spectral distribution of the radiant energy on the canceled Shot 9 evaluation. A rough spectral breakdown is obtained by mounting receiving discs in back of Corning Glass Filters No. 3-69, 2-58, 7-56, and 0-52. The filters transmit radiant energy above 5100 A°, 6300°A, 8500 A° and 3400°A, respectively. For the single station evaluation on Shot 10, goniometry of the radiant energy was considered the more

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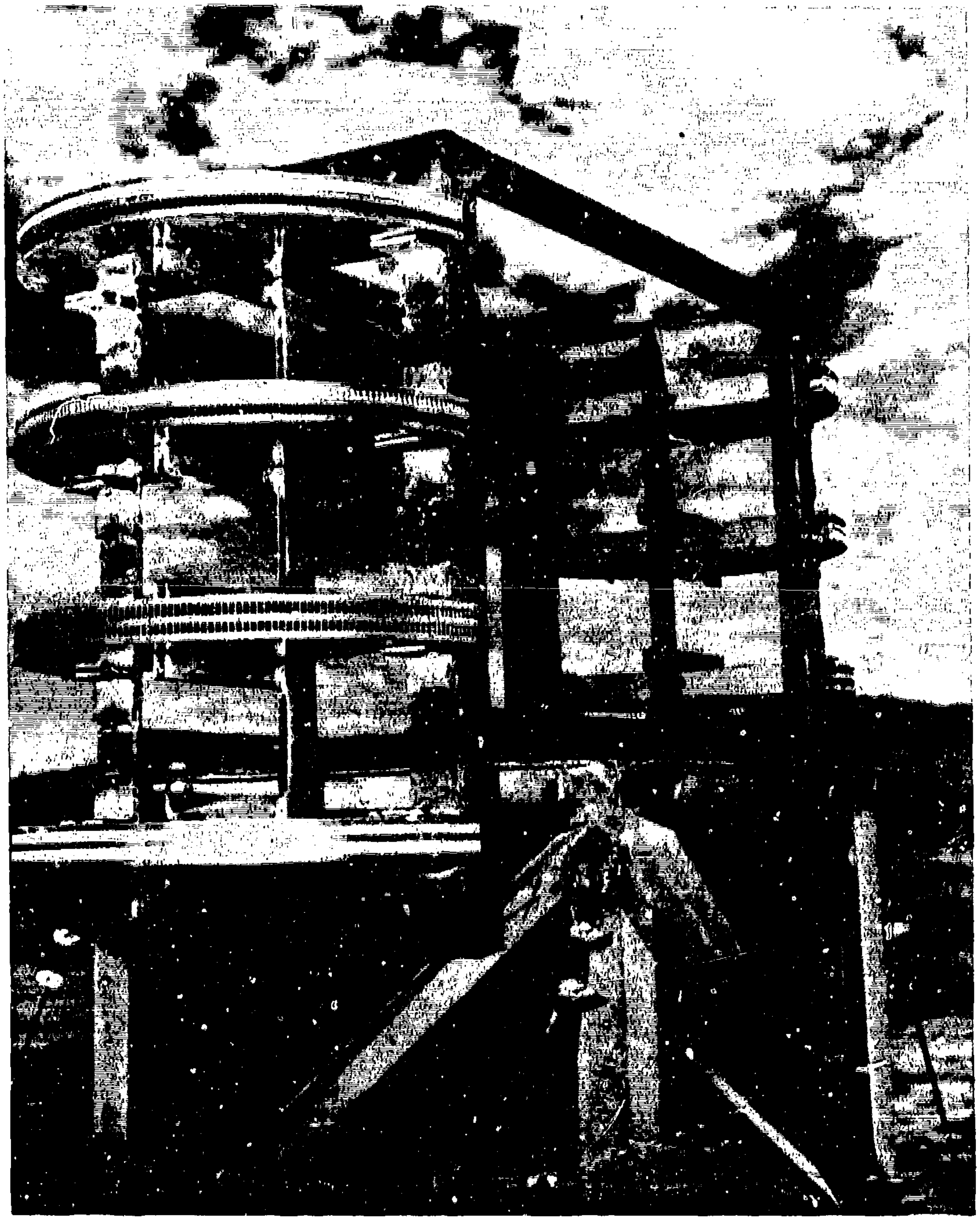

Fig. 2.8 - Field Installation of Cosine Law Attenuator Calorimeter, Mounting Rack Type A

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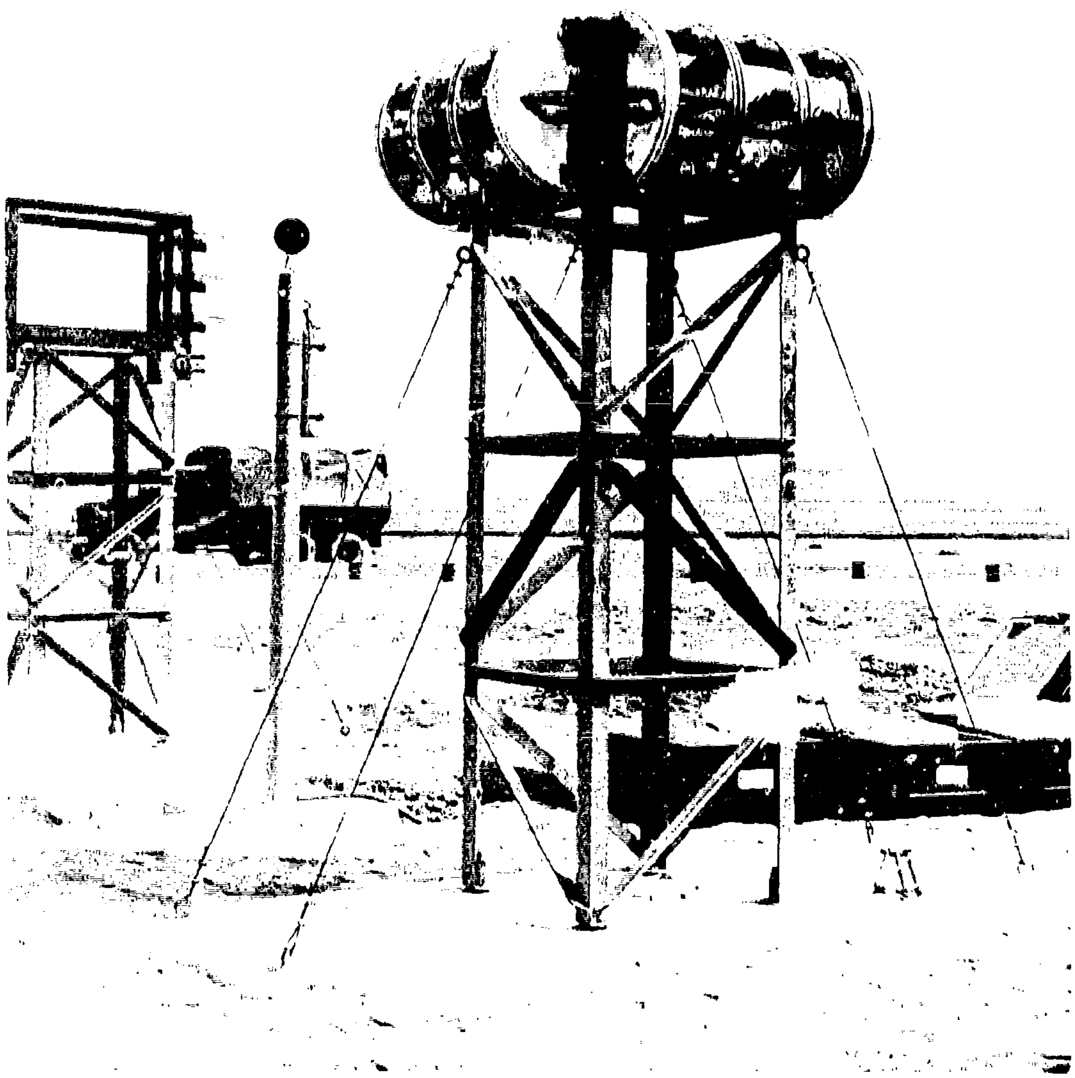

Fig. 2.9 - Field Installation of Cosine Law Attenuator Calorimeter, Mounting Rack Type B

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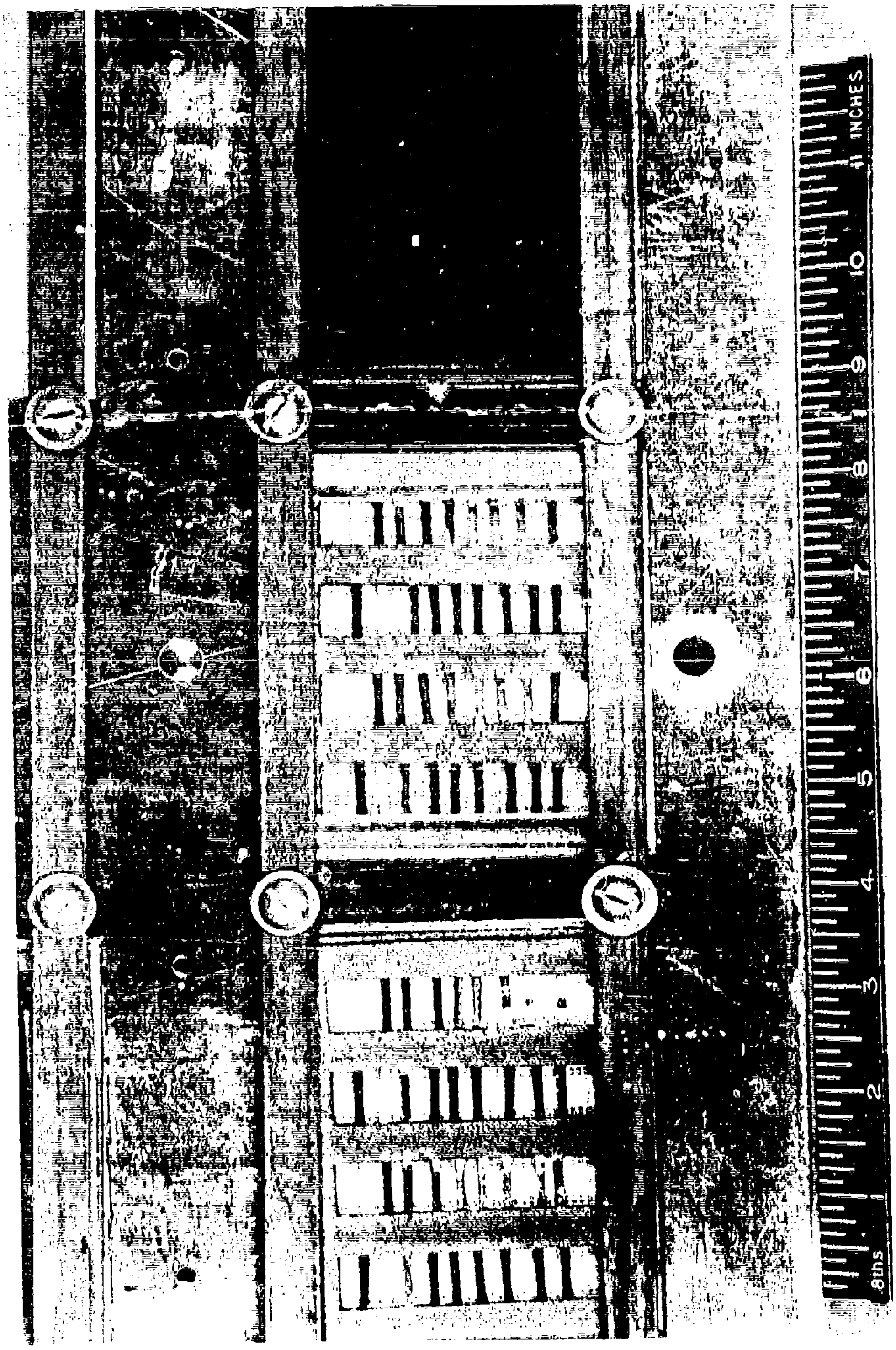

Fig. 2.10 U.S. Naval Material Laboratory Passive Receiver

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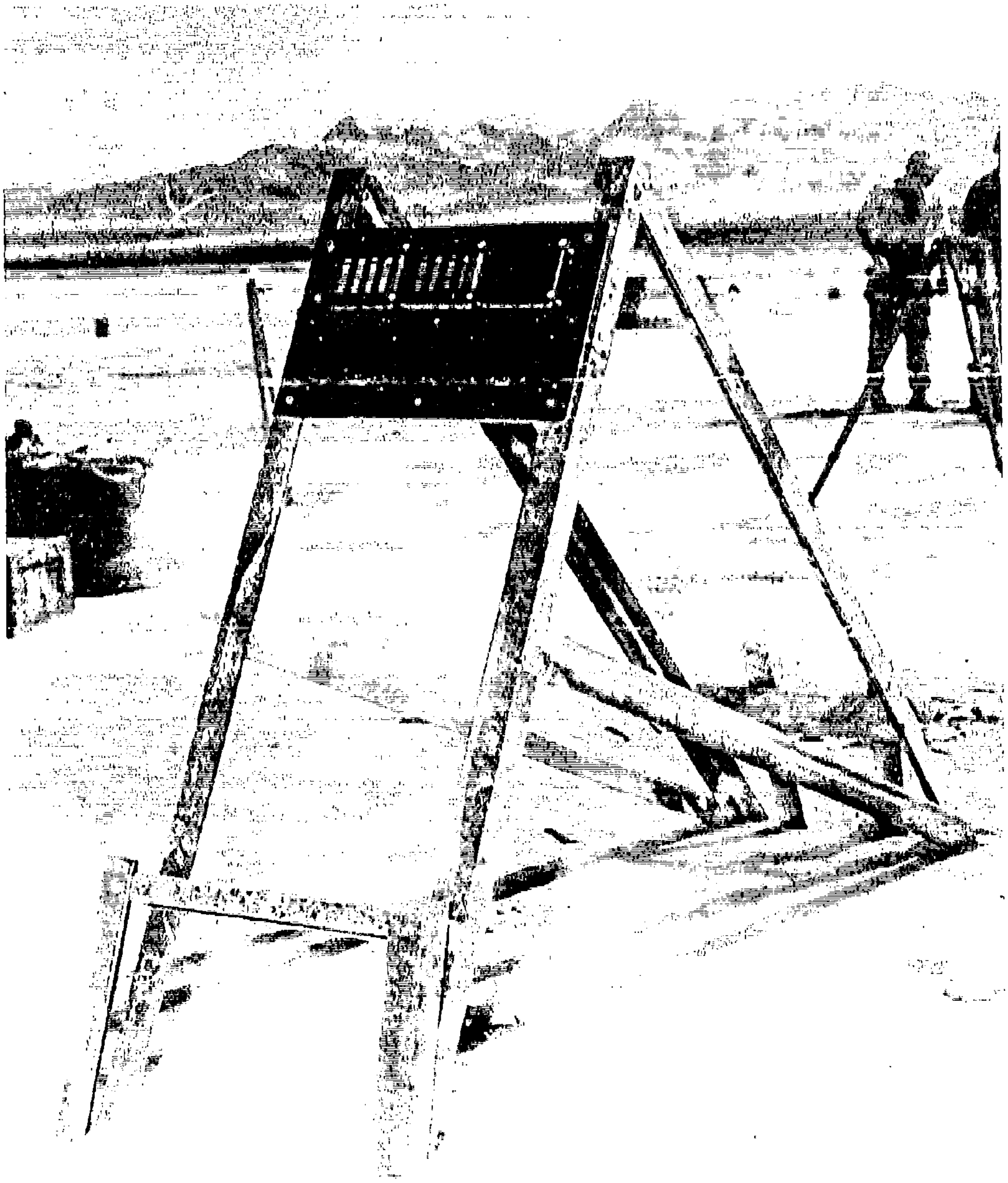

Fig. 2.11 - Field Installation of Passive Receivers

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important, and instrumentation for spectral data was not installed. Further detailed information on this method of obtaining spectral data is given in the BUSTER report for Project 2.4-1. 8/

The field installation of the calorimeter mounting assembly is shown in Fig. 2.13.

2.5 REMOTE CONTROL CIRCUITS

2.5.1 Ball Calorimeters

An H-5 sec signal from the EG&G relay was used to turn on all Esterline-Angus recorders, energize the contacts in the variable resistance manometers and start timing clocks required to perform these operations is shown in Fig. 2.12.

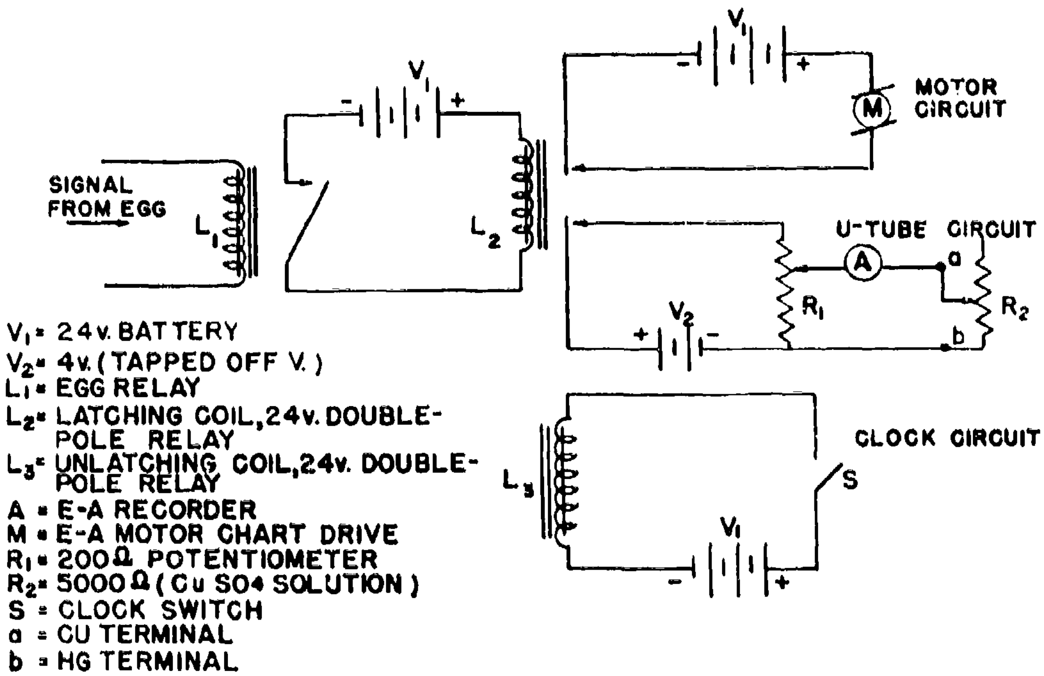

Fig. 2.12 - Circuit for Remote Control of Esterline-Angus Recorder

2.5.2 Smoke Pot, Floating, MK 5, Mod. 2

The Smoke Pots, Floating, MK 5, Mod. 2 were detonated by E-11 electric igniting fuses. For the canceled Shot 9 evaluation two control circuits were provided from the control point to EG&G relays; one circuit being provided for firing the ring of smoke pots at 2500 ft from ground zero; and, the second circuit for firing the ring of smoke pots at 4500 and 6500 ft from ground zero. A third control circuit was

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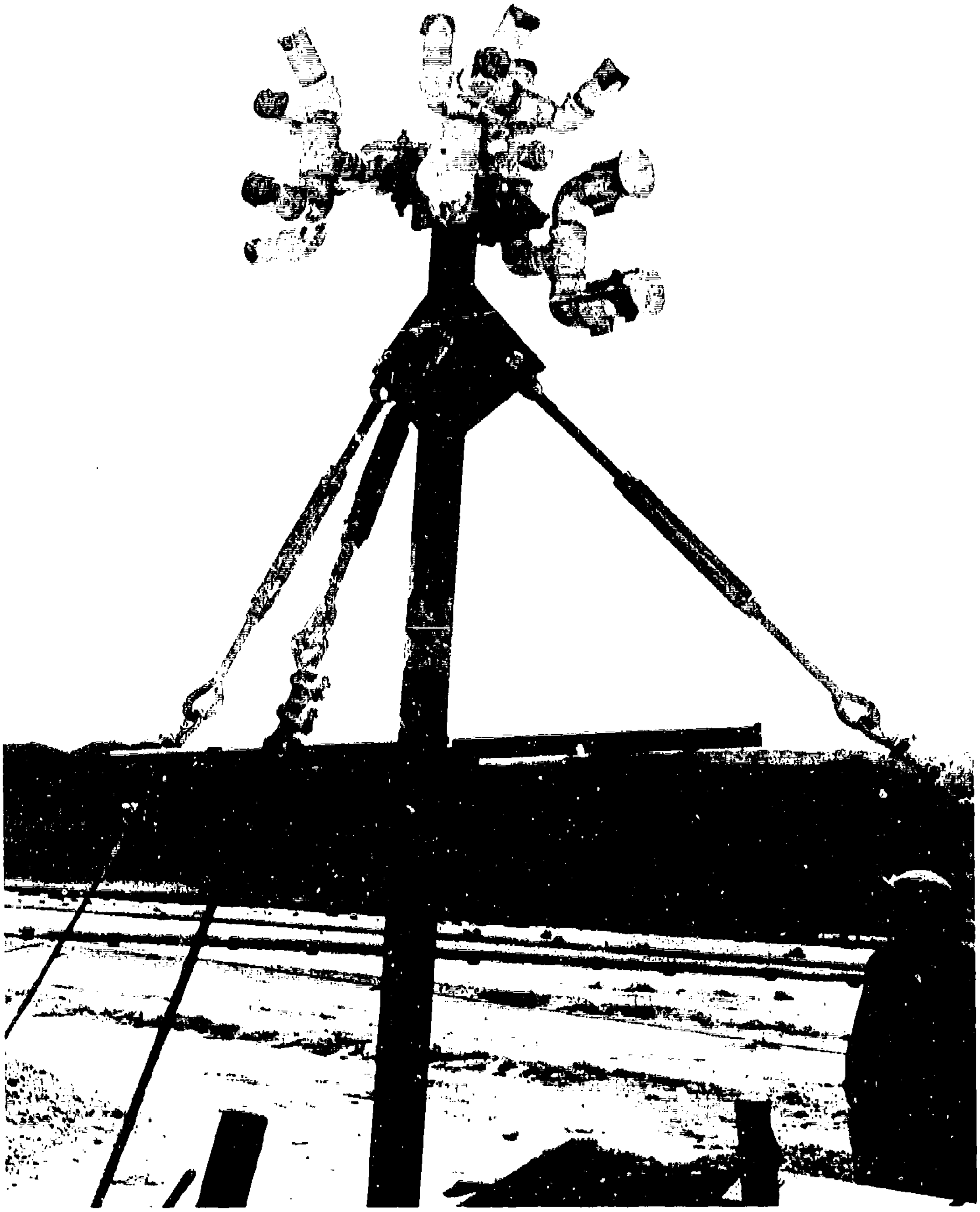

Fig. 2.13 - Field Installation of Calorimeter Mounting Assembly

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provided to fire simultaneously the secondary ring of 60 smoke pots around the 2500, 4500, and 6500 ft stations. Manually operated switches located in the control point controlled the firing of these three circuits.

For the Shot 10 evaluation, two control circuits were provided to fire the smoke pots as described in para 2.2.2.

2.5.3 E19R3 Smoke Generator

For the canceled Shot 9 evaluation, operation of the E19R3 Smoke Generators was controlled by two manually operated switches located in the control point. These switches closed EG&G relays which energized each of two sections of the smoke generator line to permit wide latitude in the section of the generators to be fired. The first circuit actuated the 35 generators on the line 1000 ft north and parallel to the instrument line and the second circuit actuated the remaining 15 generators on the arc of a circle northwest to southwest of the 2500 ft station. Wiring and flow diagrams of the firing and operating circuits of the E19R3 Smoke Generators are shown in Figs. 2.14, 2.15 and 2.16.

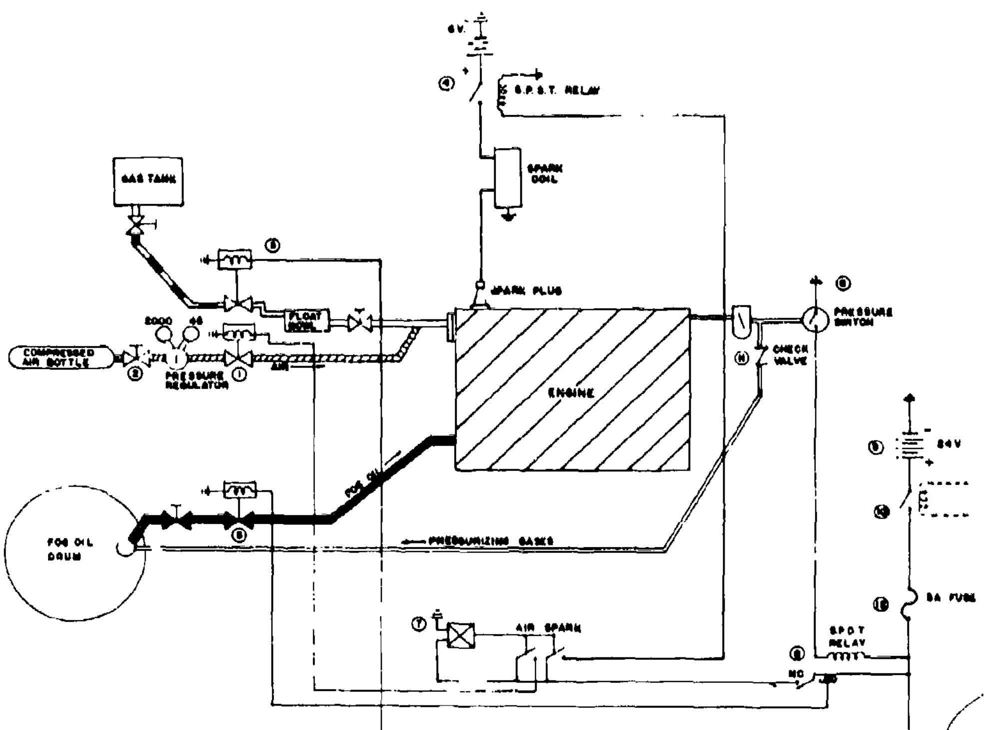

Fig. 2.14 - Schematic Flow and Circuit Diagram for Remote Control of the Smoke Generator, E19R3

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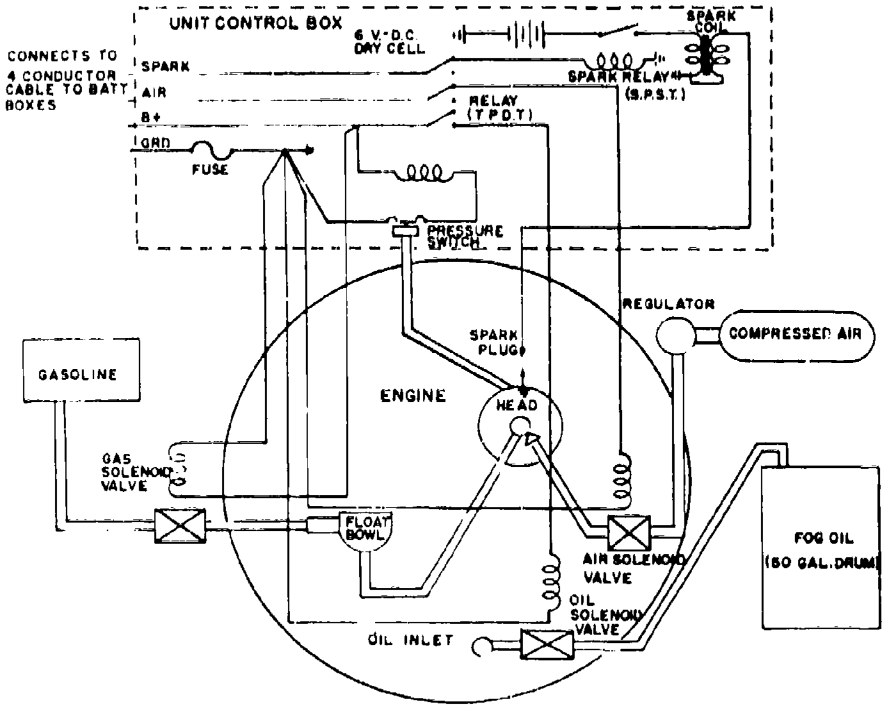

Fig. 2.15 - Control Arrangement for Smoke Generator, E19R3

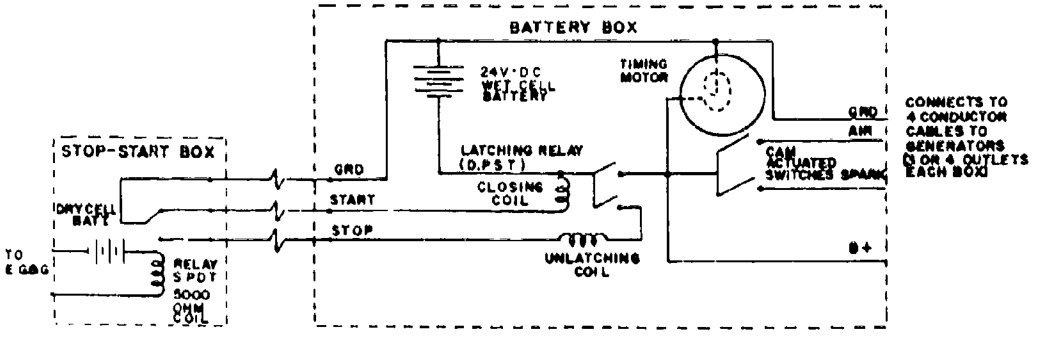

Fig. 2.16 - Circuit for Use with Smoke Generator, E19R3

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2.6 SMOKE GENERATION

2.6.1 E19R3 Smoke Generator

The E19R3 Smoke Generator (pulse jet operated), shown in Fig. 2.17, is essentially an M-3 Smoke Generator 15/ that has been modified for remote control operation. For remote control a master control switch transmits a signal to a master control box which latches a timing motor. The timing motor then indicates to the unit box the correct sequence of air and spark for proper starting.

After the generator has started and developed the required operating pressure, approximately 5 psi, a pressure switch is actuated, closing the starting air solenoid, operating the spark coil, and opening the oil inlet solenoid valve. The SGF-2 oil is injected into the tail pipe section of the pulse-jet engine and is vaporized. The vaporized oil is forced out of the smoke outlet nozzles by the thrust developed by the pulse-jet engine. Upon contact with the air, the vaporized oil condenses rapidly, forming a white fog oil aerosol.

Installation of the smoke generator in the field is shown in Fig. 2.18.

2.6.2 Smoke Pot, Floating, MK 5, Mod. 2 16/

The smoke pot, shown in Fig. 2.19, contains seven liters of SGF-2 oil and has an ammonium nitrate fuel block. The fuel block is electrically ignited by a Fuse, Electric, E-11. The burning time is approximately 10 min.

2.6.3 Determination of Smoke Concentration

Smoke concentration was determined on an average basis by determining the volume of the cloud from photography and the oil output of generators, and/or, smoke pots. A 100 fr/sec Mitchell camera was located 9200 ft south of the instrument line. The 35 mm lens of this camera gave horizontal coverage from ground zero to a point located 6500 ft, north 20° east, from ground zero. In addition, two 100 fr/sec Mitchell cameras having 50 and 152 mm lenses were located 10,000 ft south of ground zero. Two 100 fr/sec Mitchell cameras were also located almost 12,000 ft due west of ground zero. From the above photography the north-south and east-west position of the smoke screen, and the height of the smoke screen could be determined.

A variety of cameras, including aerial mapping and motion picture, were planned to be located in aircraft flying over ground zero at the time of detonation and in aircraft obtaining documentary photographs of the tests. From these vertical photographs it was planned to determine the width, breadth, and location of the smoke screen relative to ground zero.

To determine the uniformity of the cloud in the vicinity of the 2500 and 4500 ft stations from ground zero, an intermittent camera, taking still pictures, photographed vertically down onto the top of a silvered hemisphere mounted at ground level. These cameras were set to photograph the reflection of the cloud, which essentially was shown

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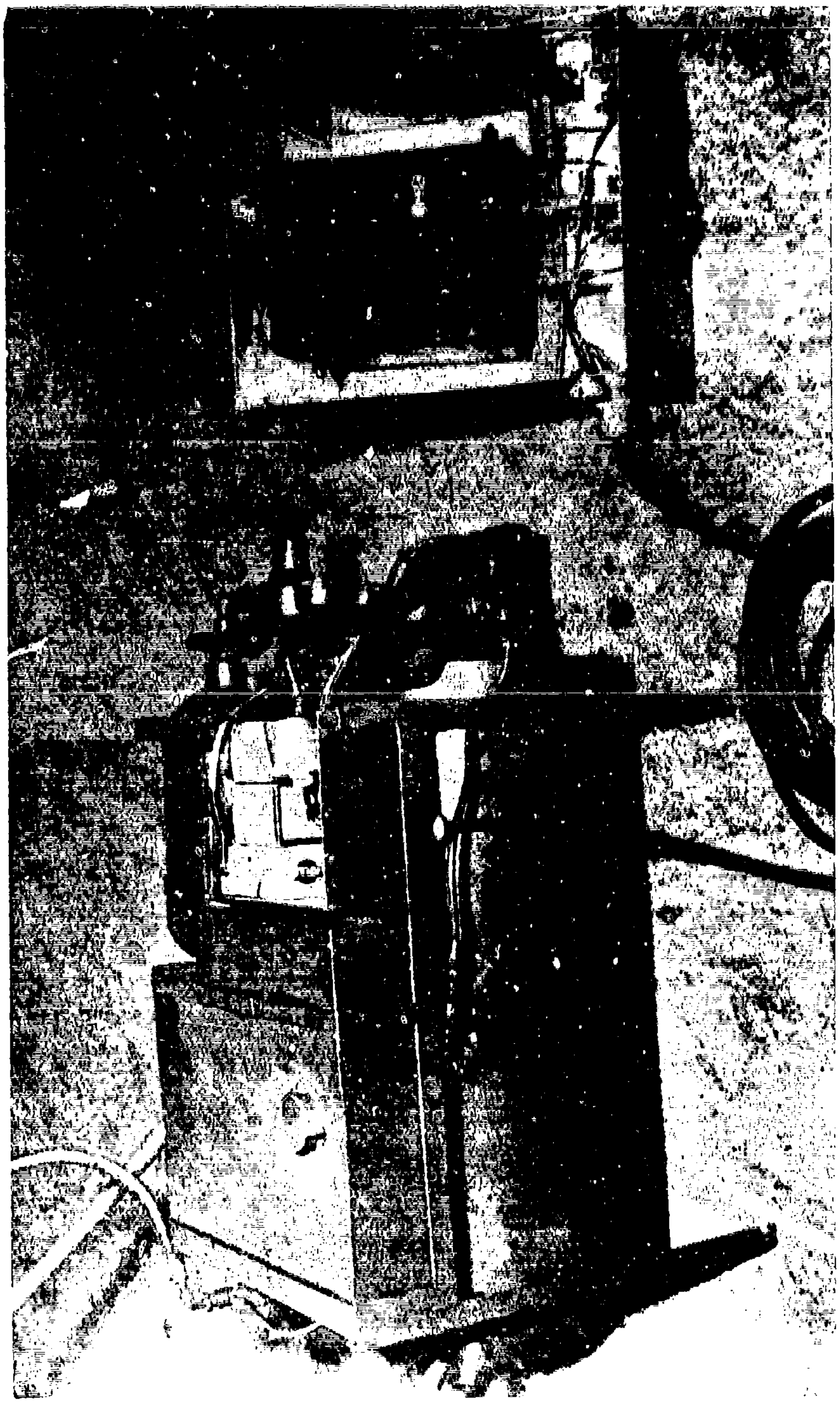

Fig. 2.17 Smoke Generator, E19R3

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Fig. 2.18 - Field Installation of Smoke Generator, E19R3

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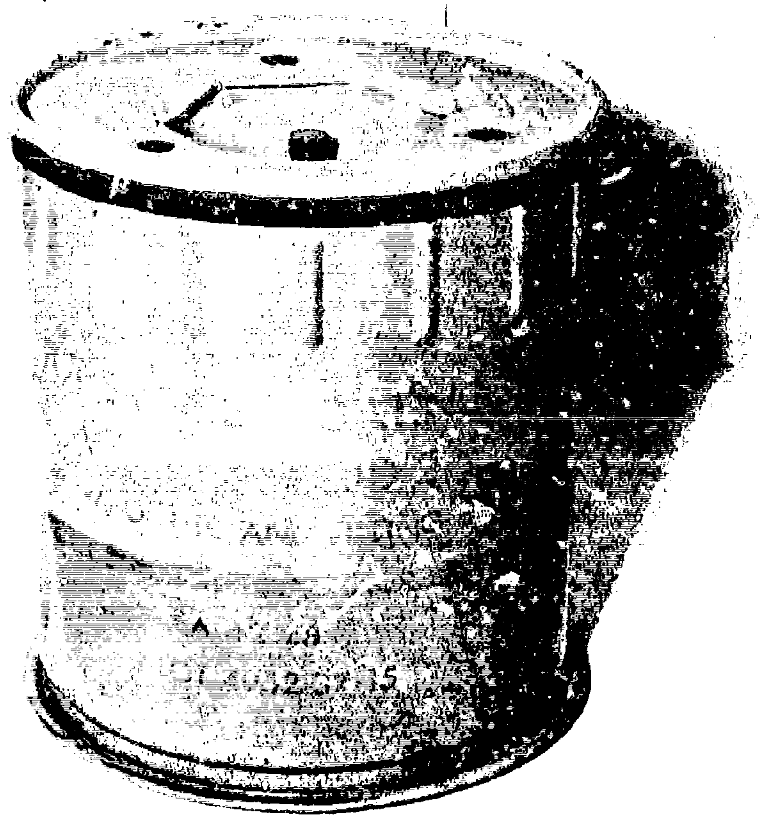

Fig. 2.19 Smoke Pot, Floating, MK 5, Mod. 2

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with 180° coverage by the hemisphere, and from these photographs the uniformity of the screen was to be determined, as illuminated by skylight.

From the average oil consumption of the smoke generators or smoke pots and the time of operation prior to the detonation, the amount of oil dispersed into the volume of the smoke screen was to be determined. The average concentration of the smoke screen was then calculated as micrograms of oil per liter of air.

During the preliminary smoke screen experiments conducted at the test site, smoke concentrations were measured 6 ft above the ground using a Mine Safety Appliance Co. Electrostatic Sampler, Model F. In all preliminary tests the electrostatic sampler was located either on the instrument line, or, in the event the wind direction moved the smoke south of the generator line, an equivalent distance 1000 ft, downwind of the smoke generators.

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CHAPTER 3

TEST RESULTS

3.1 WEATHER AND OPERATIONAL CONSIDERATIONS FOR SHOT 9

The wind direction and velocity remote reading gage records are shown in Fig. 3.1, and the pertinent condensation of the data are given in Table 3.1.

TABLE 3.1 - Condensation of Weather Record
8 May 1953

TIME (PDT)	WIND VELOCITY (mph)	DIRECTION (deg true)
0700	4½	320
0705	5½	355
0710	4½	25
0715	4½	25
0720	4½	20
0725	5	20
0730	5	30
0735	4½	35
0740	2½	45
0745	2½	55
0750	1	60
0800	1½	65
0805	calm	75
0810	calm	75
0812	calm	90
0815	calm	275
0818	calm	170-285
0819	2½	260-295
0821	1	165-290
0823	calm	205-290
0824	calm	90
0827	1	210
0828	6	210
0829	7	180
0830	7	180

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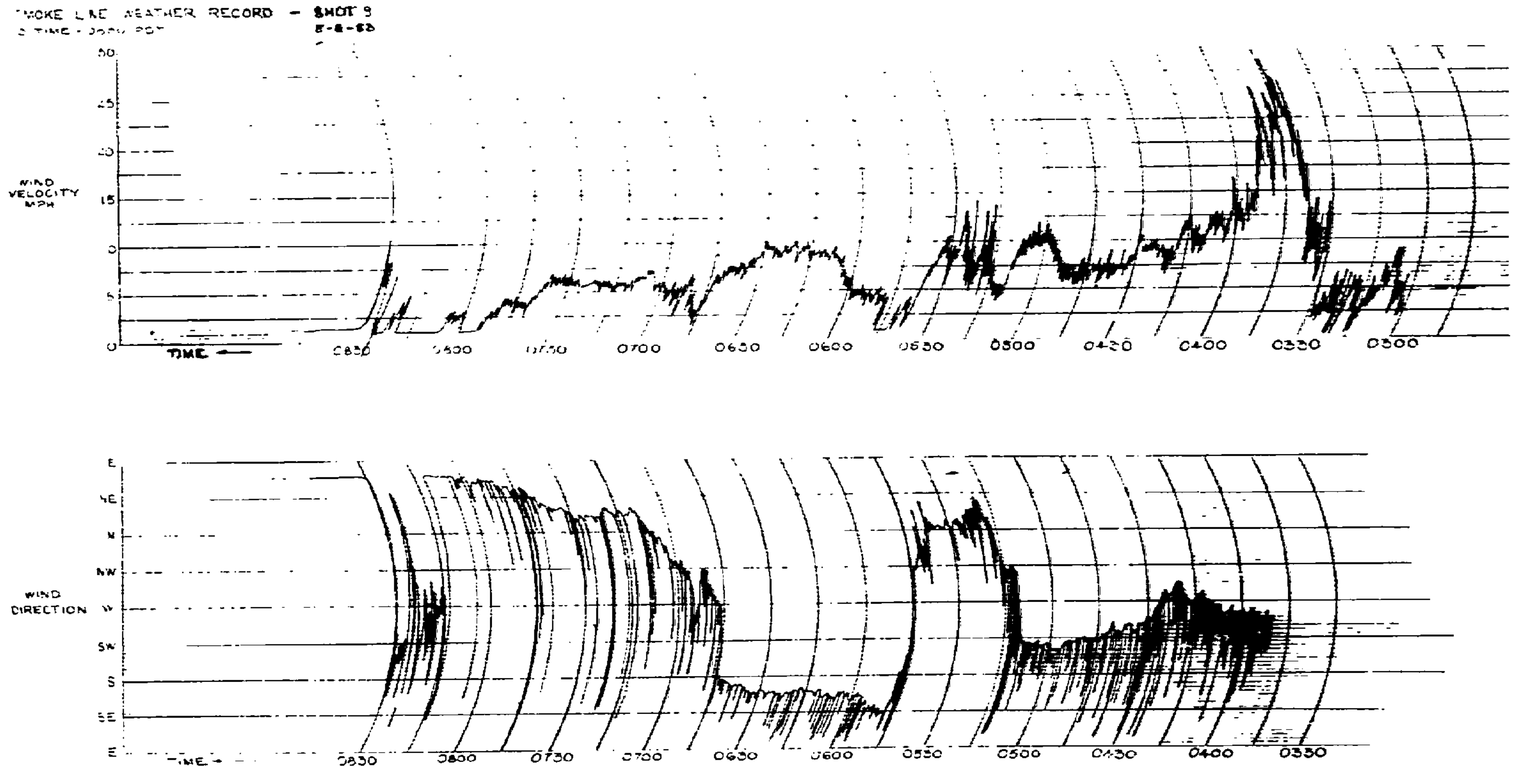

Fig. 3.1 Wind Direction and Velocity Charts - Shot 9

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It is to be noted that conditions until 0710 PST were satisfactory for establishing a smoke screen with the 50 smoke generators; that conditions from 0710 until 0805 were satisfactory for establishing a smoke screen with a single ring of smoke pots fired at H-3 min around each of the primary instrument stations; and, that conditions, based upon weather considerations only, from 0805 until 0830 were satisfactory for establishing the smoke screen with smoke pots fired at H-3 min. However, because of the calm condition from 0805 until 0815, and the variable direction condition from 0815 until 0824, apprehension was raised over the drift direction of the smoke screen in the event of a non-drop on the first target run at 0830. The aircraft pattern in the event of a non-drop called for a second bomb run with a detonation time of 0845. The smoke pots, if fired at 0827, would continue producing smoke for from 8 to 12 min, until approximately 0839. Should the drift be to the west, as the northeast to east direction indicated from 0805 until 0815, then under the calm condition indicated from 0805 until 0827 smoke might not clear the test area west of ground zero for a second target run and drop at 0845. The decision was therefore made at approximately 0825-0826 not to fire the smoke pots, and not to risk calling off the operation in the event the aircraft did not drop at 0830 and smoke did move into the target area west of ground zero.

The weather conditions that prevailed at 0828 were satisfactory for firing the smoke pots and continued satisfactory until shot time when the wind gage was damaged by blast.

3.2 DATA OBTAINED FROM LIMITED EXPERIMENT ON SHOT 10

3.2.1 Meteorological Situation

The meteorological situation prior to shot time was quite variable and shifting during the one hour period prior to detonation. The wind direction and velocity charts are shown in Fig. 3.2, and pertinent data are given in Table 3.2.

TABLE 3.2 - Condensation of Weather Record
25 May 1953

TIME (PDT)	WIND VELOCITY (mph)	DIRECTION (deg true)
0730	1½	195
0735	1½	250
0740	2½	305
0745	2½	20
0750	2½	20
0755	3½	170
0800	6½	250
0805	6½	255
0810	6½	280
0815	7½	305

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TABLE 3.2 (Cont'd)

TIME (PDT)	WIND VELOCITY (mph)	DIRECTION (deg true)
0816	4½	270
0817	5	315
0818	1½	325
0819	1½	350
0820	4	350
0821	1½	340
0822	3	340
0823	3	340
0824	3½	350
0825	4	320
0826	3½	20
0827	3½	350
0828	4	350
0829	4	15
0830	3	15

It should be noted during the period of 0800 to 0818 that the wind direction was gradually shifting from the southwest to the northwest. During this period the velocity was dropping from 6 to 8 mph to 1½ to 4 mph. During the period of 0818 to 0821 the wind velocity dropped to 1½ mph with the direction almost from due north. The velocity increased again to 3 to 4 mph during the period of 0822 to 0830 and, although the direction was quite variable, the direction trend continued from the north shifting to the northeast. The decision was made to fire all smoke pots from 500 to 4600 ft from ground zero.

3.2.2 Smoke Screen Dimensions and Locations

The position and extent of the fog oil smoke screen at zero time was required to estimate the volume of the screen for concentration determination. The positions of the carbon and fog oil smoke screen at zero time was required to determine the extent of the interference of the carbon smoke screen with atomic bomb thermal radiation falling directly on the fog oil smoke screen. The determination of the relative positions was seriously hampered by lack of aerial mapping photographs taken from aircraft flying over ground zero at H-hour. Through an error in aircraft scheduling these aircraft were not in the test area at H-hour.

Ground station photography obtained excellent records of the smoke screens from the south and west during the period of approximately H-5 sec through H-hour. These records were obtained at 100 fr/sec from cameras located nominally west and south looking at ground zero, and 18° east of south, viewing the entire smoke screen area east of ground zero. In addition, one set of still and motion picture photographs was obtained from a documentary aircraft flying at 10,000 ft MSL south of ground zero at 11 miles slant range. From these photographs, sketches of the smoke screen outlines and a composite plan view of the smoke screen positions were prepared to scale. This composite plan view is

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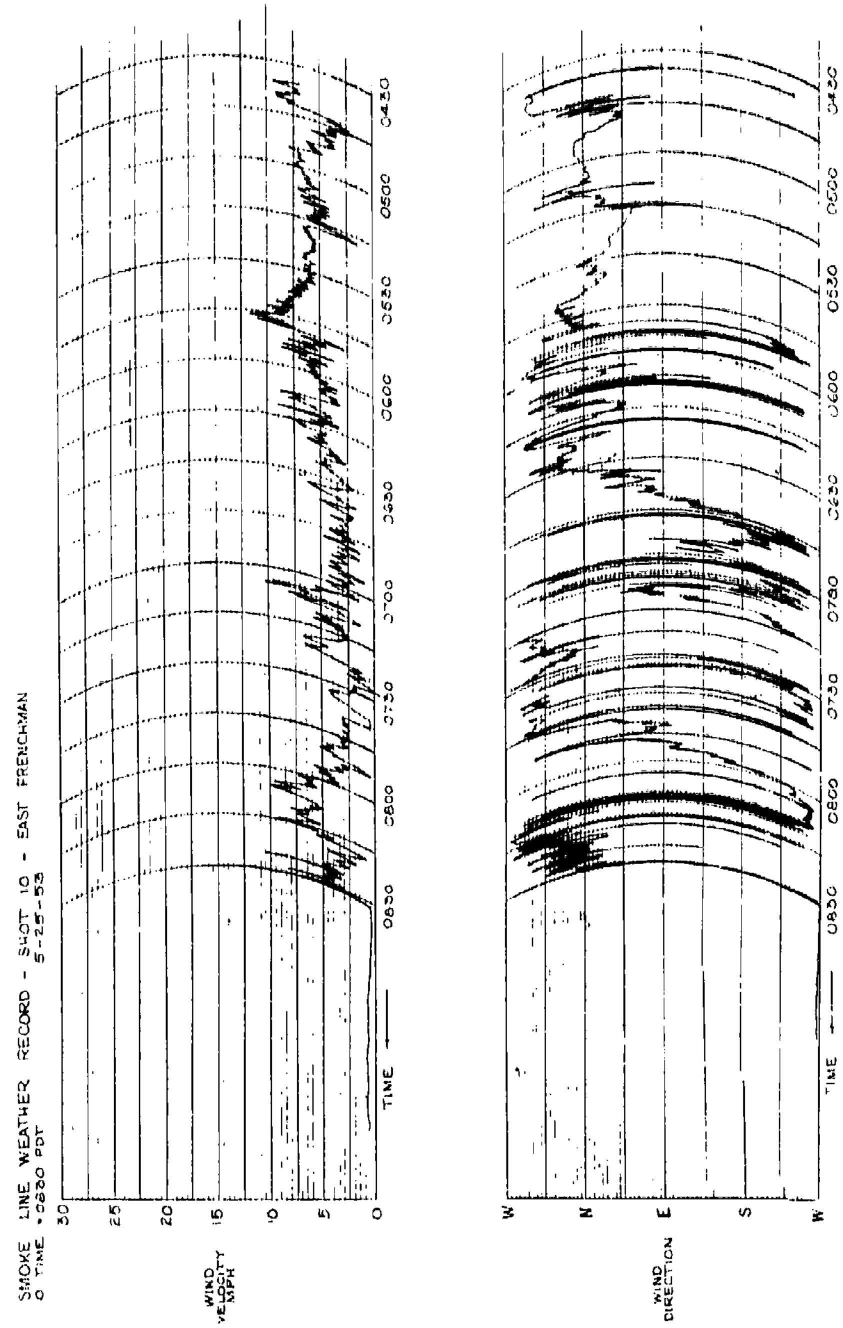

Fig. 3.2 Wind Direction and Velocity Charts - Shot 10

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shown in Fig. 3.3. A composite vertical view of the smoke screens is shown in Fig. 3.4, on a line through air zero and the fog oil smoke screen instrument station. An aerial photograph of the smoke screens at approximately H-5 sec is shown in Fig. 3.5. The analysis and reproduction of the fireball photographs are shown in the Project 8.4-2 Final Report. 19/

As shown in Figs. 3.3 and 3.4 there is no doubt that the carbon smoke screen intercepted the thermal radiation incident upon the fog oil smoke screen. From Fig. 3.4 it is estimated that the direct path of radiation through the carbon smoke screen was 1550 ft.

3.2.3 Smoke Screen Concentration

The best estimate of the quantity of fog oil which contributed to the reduction of thermal radiation can be obtained from estimates of the distance traveled by the cloud and the total amount of smoke generated by the pots during the three minute operating time prior to detonation. For purposes of estimation the output of fog oil from each pot was assumed to be 7 liters in 10 min, the specific gravity of fog oil was assumed 0.9, the operating time prior to detonation was 3 min, and the downwind travel of the cloud was 480 meters as shown in Fig. 3.3. Based upon cloud travel information, 64 of the 175 smoke pots installed and fired on the 200 ft and 300 ft circles provided smoke in front of the instrument station. The calculated total quantity of fog oil generated in three minutes was 1.2×10^5 grams. Based upon a downwind travel of 480 meters, the average quantity of fog oil per unit path normal to the wind direction was, therefore, 250 grams/meter of downwind travel. With one-half the width of the cloud estimated at 65 meters at the point where thermal radiation was incident upon it, the average path length-concentration of the smoke screen was 250/65 or 3.8 grams/sq meter. Assuming that the direct slant path for thermal radiation is approximately 165 meters, as shown in Fig. 3.4, the estimated average concentration, if uniformly dispersed, would be 23 micrograms/liter. Because of the circular pattern of the smoke pots the concentration within the cloud could be expected to be exceedingly non-uniform. However, the path length-concentration can be considered indicative of the order of magnitude of smoke which achieved the 85 to 90 per cent attenuation of thermal radiation.

3.2.4 Thermal Flux Measurements Under the Smoke Screen

Forty-eight Cosine Law Attenuator Calorimeters were exposed at Station 422-A (2166 ft from planned ground zero). These calorimeters were arranged as shown in Figs. 2.8 and 2.9 to measure the spatial distribution of the thermal flux along the circumferences of the three major axes of a sphere. All calorimeters, regardless of orientation were unaffected by the thermal flux. This indicates that the total integrated thermal flux received from a solid angle of 2π steradians, irradiating the calorimeters, was less than 0.7 cal/sq cm. Due to the high wind conditions existing after the calorimeters were emplaced, a considerable quantity of dust was probably deposited upon the indicating surfaces. This dust has in all probability changed the

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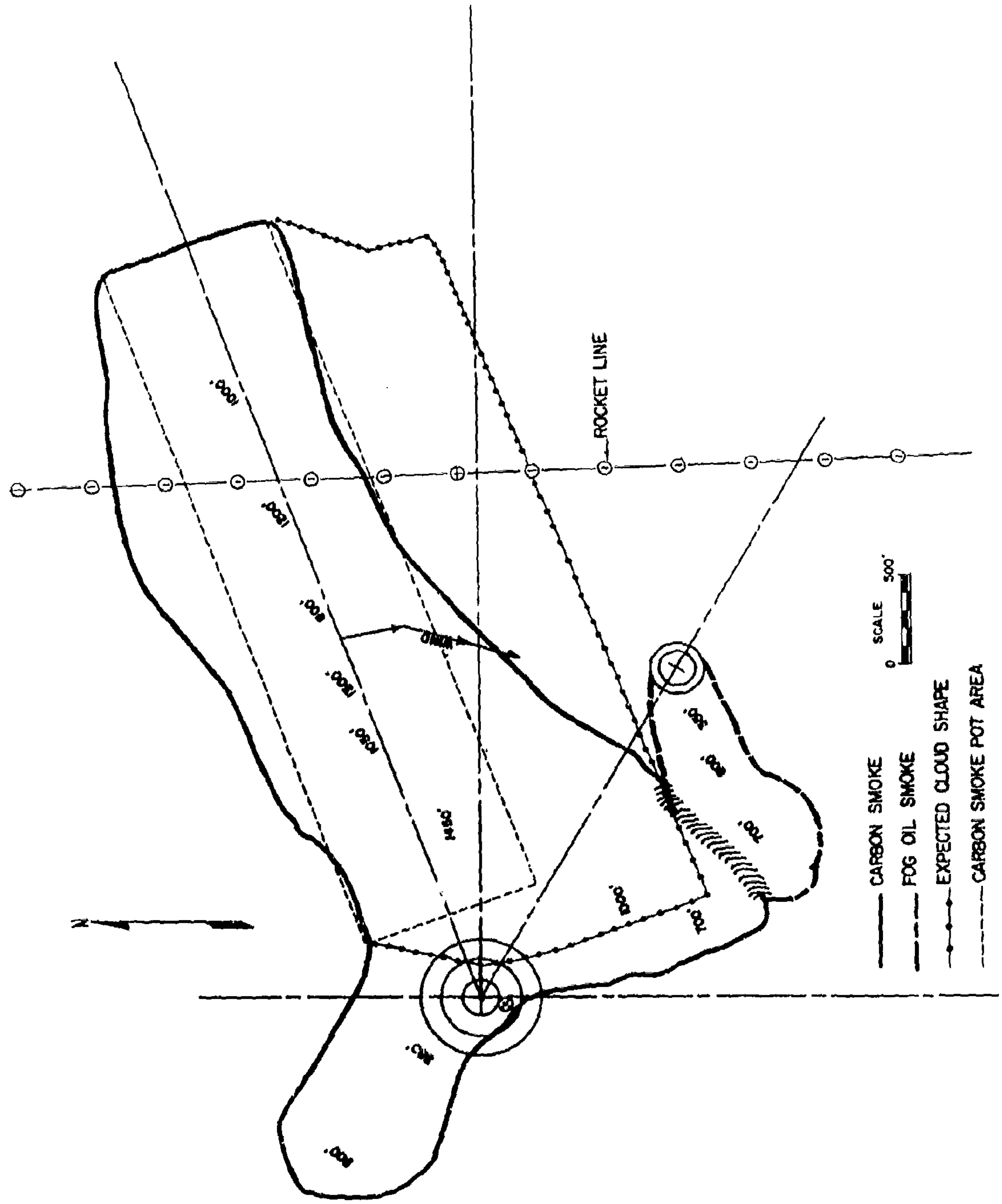

Fig. 3.3 Composite Plan View of Smoke Screen Positions

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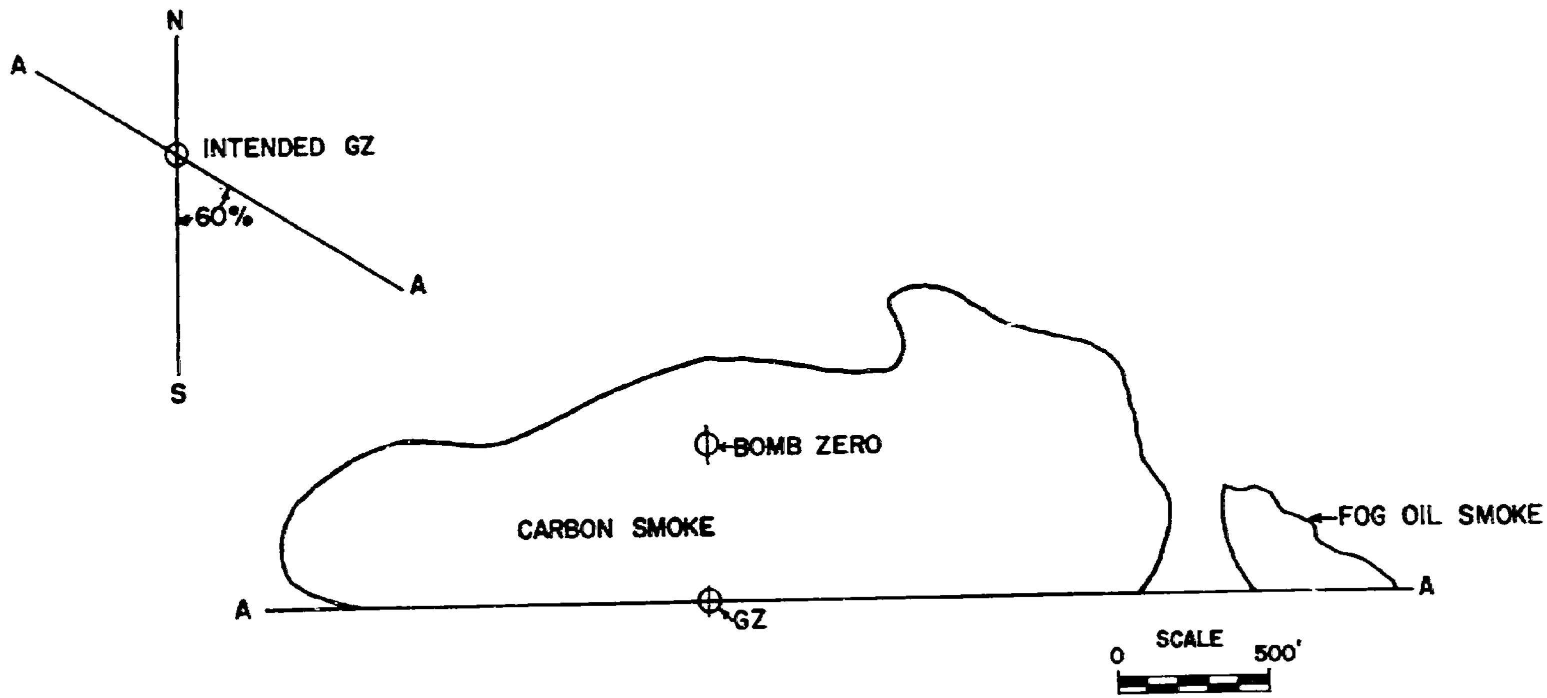

Fig. 3.4 Sketch of Vertical Extent of Smoke Sources Along Line From Ground Zero Through Fog Oil Instrumentation Stations

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Fig. 3.5 Aerial View of Smoke Screens

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calibration values of the papers and fabrics. The quantitative effect of this dust is not known but it may be assumed that an error not exceeding 50 per cent is introduced in the readings. Thus the maximum flux is less than 1 cal/sq cm.

The NML passive receiver unit, emplaced at Station 422-A to measure the spectral distribution of the radiant energy in three broad representative wave length regions, was badly damaged by blast and no spectral distribution measurements were obtained. However, since the flux measured by the Cosine Law Attenuator Calorimeter was less than 1 cal/sq cm, and the lowest detectable flux which can be measured by the spectral receiver is 0.7 cal/sq cm, it can be assumed no data would have been obtained.

Twelve NRDL Field Calorimeters were used to determine the spatial distribution of the radiant energy in one quadrant of a sphere. The data obtained by these calorimeters are shown in Table 3.3.

TABLE 3.3 - Thermal Flux Under the Fog Oil Smoke Screen
(U. S. NRDL Field Calorimeters)

Orientation to G.Z.	Field of View (degrees)	Filter	Total Energy to Station (cal/sq cm)
vertical	90	quartz	0.2
vertical	180	none	0.6
up 30°	180	none	0.8
up 60°	180	none	0.8
at G. Z.	90	quartz	0.4
at G. Z.	180	none	0.8
away fr G.Z.	180	none	0.4
rt 90°, horiz.	90	quartz	0.3
rt 90°, up 45°	180	none	0.3
rt 90°, horiz.	180	none	0.3
rt 60°, horiz.	180	none	0.3
rt 30°, horiz.	180	none	0.9

The spatial distribution of radiant energy, as indicated by the above data, are shown in Figs. 3.6 and 3.7.

The results obtained by the Gas Calorimeters located at Station 422-A similarly indicated thermal fluxes of less than 0.5 cal/cm^2 ± 50 per cent received from a solid angle of approximately 4 π steradians. Two of the four instrument records at this station were damaged by blast.

3.2.5 Thermal Flux Measurements Out of the Smoke Screen

The basic thermal data in the clear area were obtained by the NRDL. 17/ These data indicate that the thermal flux at the fog oil smoke instrumentation station would have been 57.5 ± 5.0 cal/sq cm without smoke present.

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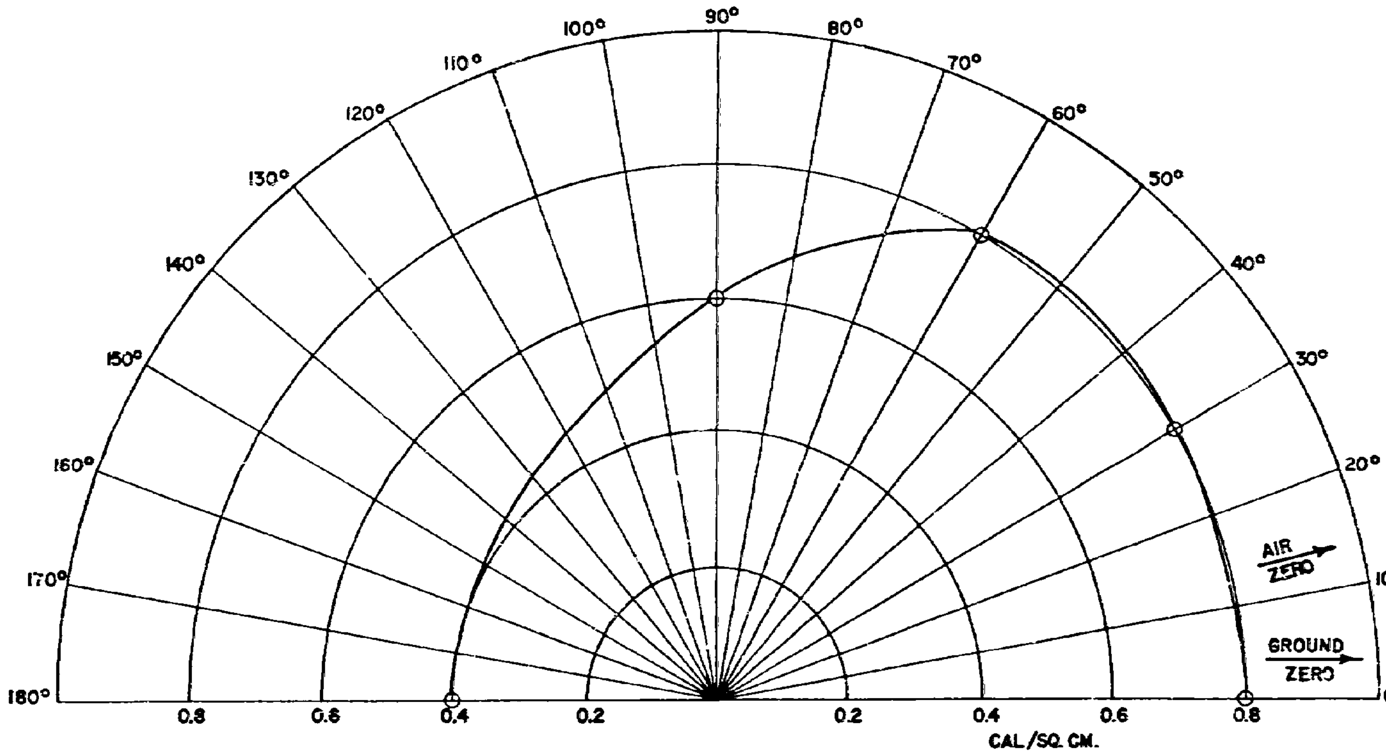

Fig. 3.6 Vertical Spatial Distribution of Thermal Flux Received Under the Smoke Screen

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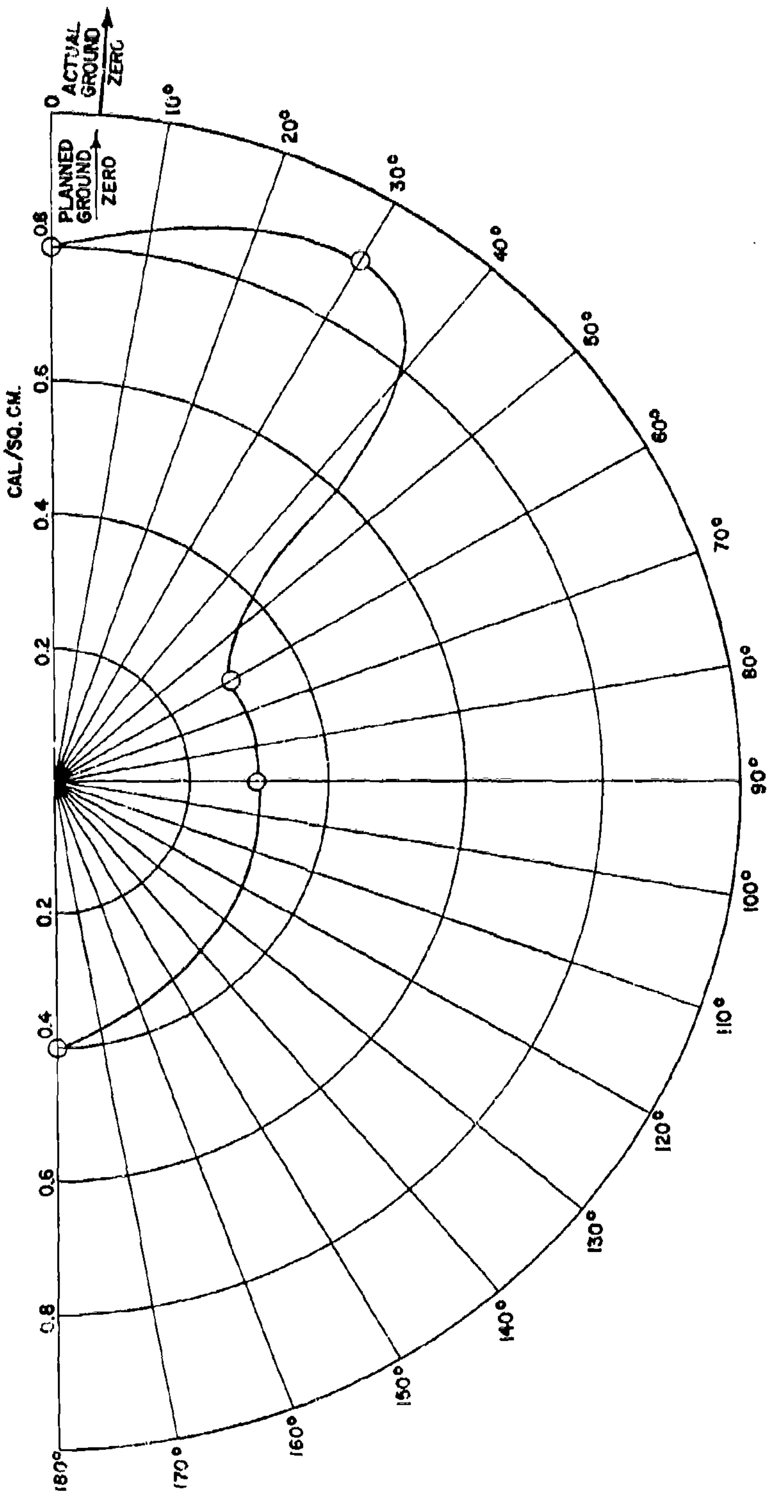

Fig. 3.7 Horizontal Spatial Distribution of Thermal Flux Received Under the Smoke Screen

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The data obtained by the Gas Calorimeters located at the stations 2500 ft, 4000 ft, and 5000 ft from the planned ground zero are given in Table 3.4. It has been calculated previously that the contribution of ground reflectance thermal flux to these 4π steradian spherical detectors was approximately 20 per cent. The studies of the NML on this subject were used as the basis for the calculation of this value. 18/

3.3 CRL Ball Calorimeter Data for Shot 9

The basic thermal data in the clear area were obtained by the NRDL. 17/ In addition CRL ball calorimeters had been located at stations 2500 ft, 4000 ft, and 5000 ft from the planned ground zero on the west, or non-smoke side. Also CRL ball calorimeters were located on the east, or planned smoke side, of ground zero at distances of 2500 ft, 3500 ft, 4500 ft, 5500 ft, and 6500 ft from the planned ground zero. The calorimeters were mounted $6\frac{1}{2}$ ft above the ground on the smoke side and 15 and 25 ft above the ground on the non-smoke side. The data obtained by the CRL ball calorimeters are given in Table 3.5.

TABLE 3.4 – Unattenuated Thermal Flux Determined By the Gas Calorimeter for Shot 10

Height Above Ground (feet)	Distance From Planned Ground Zero (feet)	Slant Range	Recorded Flux (cal/cm^2)	Corrected A/ Flux (cal/cm^2)
25	5000	4943	28.2	22.5
25	5000	4943	26.1	20.9
15	5000	4943	25.0	20.0
15	5000	4943	23.2	18.6
25	4000	3951	36.7	29.4
25	4000	3951	37.0	29.6
25	2500	2427	93.3 B/	74.6 B/
25	2500	2427	78.3 B/	62.6 B/

A/ Recorded Flux less 20 Per Cent Contribution From Ground Reflectance.
B/ Maximum recorder readings possibly changed while equipment was lowered to ground by derrick.

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TABLE 3.5 - Total Thermal Energy Determined By CRL Ball Calorimeter on Shot 9

Distance From Planned G. Z. (feet)	Actual Slant Range (feet)	Recorded Flux (cal/cm^2)	Corrected Flux A/ (cal/cm^2)
2500 W	3570	95.0	76.0
4000 W	4744	58.4	46.7
4000 W	4744	51.1	40.9
5000 W	5612	43.3	34.6
5000 W	5612	37.9	30.4
5000 W	5612	35.1	28.1
2500 E	3784	83.0	66.4
2500 E	3784	85.2	88.2
3500 E	4574	47.1	38.0
3500 E	4574	50.2	40.2
4500 E	5433	38.2	30.6
5500 E	6334	29.0	23.2
5500 E	6334	24.5	19.6
5500 E	6334	28.2	22.6
6500 E	7261	20.7	16.6
6500 E	7261	21.0	16.8
6500 E	7261	21.0	16.8
6500 E	7261	19.3	15.5

The CRL ball calorimeter readings were in agreement to ± 10 per cent at each station. On the east side of ground zero, where the ball calorimeters were located $6\frac{1}{2}$ ft above the ground, the readings are generally lower than the readings obtained at the same slant range on the west side of ground zero, where the ball calorimeters were located at 15 ft and 25 ft. This is believed due to (1) the partial thermal shielding of the $6\frac{1}{2}$ ft calorimeters by preshock dust, and (2) the smaller contribution of ground scattered radiation to calorimeters located closer to the ground.

Comparison of the CRL ball calorimeter data with the basic thermal data in the clear areas was not considered meaningful because the angle of reception of the ball calorimeter is 4 π steradians and the basic data are obtained with π steradian detectors oriented at the planned air zero. The contribution of ground and air-scattered radiation to a 4 π steradian detector cannot be determined to sufficient accuracy to permit comparison with the basic thermal data. As shown in Tables 3.4 and 3.5, an average value of 20 per cent was established for the Nevada Proving Ground conditions. Actually, the contribution by ground scattered radiation varies with the distance for ground zero and local soil conditions. Therefore, it was considered that a more exact calculation was not warranted.

A/ Recorded Flux Less 20 Per Cent Contribution From Ground Reflectance.

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CHAPTER 4

DISCUSSION

The data obtained by this project indicate that the thermal flux received under the smoke screen was less than 0.7 to 1.0 cal/sq cm. The data obtained by the NRDL field calorimeters are the most accurate data on the thermal flux. These data indicate the flux to be 0.8 ± 0.1 cal/sq cm as received by a 2π steradian detector, and 0.3 cal/sq cm as received by a π steradian detector. The difference between the π and 2π steradian detector results is due to the high degree of scattering of radiation within the fog oil smoke. The thermal flux without smoke present at this distance was 57.5 ± 5.0 cal/sq cm. On this basis the reduction of thermal radiation was 98.6 ± 0.3 per cent.

The analysis of the photographic coverage of the test has shown that the carbon thermal absorbing smoke screen, 19/ also evaluated on Shot 10, intercepted the thermal radiation incident on the fog oil smoke screen. Thus, some of the reduction calculated above is due to absorption of thermal radiation by the carbon smoke screen. The analysis of the photographs to determine the location of the smoke screens given in Section 3.2.2, has indicated that the direct path of thermal radiation through the carbon smoke screen was of the order of 1550 ft.

An estimate can be made of the amount of thermal radiation absorbed by the carbon smoke screen. Thermal flux data taken solely under the carbon smoke screen indicate that 97.4 per cent reduction was obtained at a slant range of 2640 ft. 19/ The photographic coverage indicated that the carbon screen extended from air zero to this station. The following two assumptions are necessary to obtain this estimate: (1) the carbon smoke screen concentration was uniform from air zero to the 2640 ft slant range; and, (2) the absorption of thermal radiation by the carbon smoke can be described by an exponential law of the following form

$$1 - I/I_0 = e^{-kx}$$

where, I/I_0 = transmission of thermal radiation

x = distance through smoke screen.

Laboratory experiments have shown that such an exponential relationship will describe the attenuation of thermal radiation by a carbon smoke

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screen. 20/ Based upon 0.974 absorption through 2640 ft of carbon smoke, k is equal to 3.65/2640. Therefore, the absorption through 1550 ft is 0.882 or 88.2 per cent.

Thus, 11.8 per cent of 57.5 cal/sq cm, or 6.8 cal/sq cm, was transmitted through the carbon smoke and was incident upon the fog oil smoke cloud. Since the thermal flux measured at the station under the fog oil smoke screen was 0.8 cal/sq cm, the actual attenuation of thermal radiation due to the fog oil smoke screen was of the order of 85 to 90 per cent.

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CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

1. An analysis of the photographic records of this experiment has shown that the carbon smoke screen, also evaluated in Shot 10, has contributed to the attenuation of thermal radiation measured under the fog oil smoke screen.

2. The thermal flux measured under the fog oil smoke screen was less than 0.7 to 1.0 cal/sq cm, with an accurate reading of 0.8 ± 0.1 cal/sq cm obtained with 2 π steradian copper disc calorimeters. The unattenuated thermal flux at this slant range would have been 57.5 ± 5.0 cal/sq cm.

The following estimates are indicated concerning the reduction of thermal radiation due to the carbon and fog oil smoke screens individually. These concern the results obtained by the single instrument station located 2238 ft from air zero. It should be realized that the data were obtained by instruments working at the extreme lower range of their accuracy because of the high reduction obtained, and that the concentration of the two smoke screens and reduction due to carbon smoke alone could only be estimated. In addition, the fog oil smoke screen was of limited dimensions estimated at 1500 ft long and 300-500 ft wide, and loss of radiation through edge effects was not evaluated.

3. It is estimated that the carbon smoke screen reduced the incident thermal flux upon the fog oil smoke screen by 88 per cent to 6.8 cal/sq cm.

4. It is estimated that the fog oil smoke screen reduced thermal radiation from an estimated 6.8 cal/sq cm to 0.8 cal/sq cm at the single instrument station 2238 ft slant range covered by a limited smoke screen.

5. On the basis of this analysis of the reduction due to the carbon smoke screen, it is estimated that the attenuation of thermal radiation by the fog oil smoke screen was 85 to 90 per cent at 2238 ft from air zero.

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5.2 RECOMMENDATIONS

It is recommended, because of the cancellation of the full-scale experiment originally planned for Shot 9 and the interference of the carbon smoke screen with the successful conduct of the limited experiment on Shot 10, that conduct of the original experiment planned for Shot 9 be considered for a future atomic weapons test to confirm the data in Conclusion 5, above.

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